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Receptor Model Technical Series. Volume I Overview of Receptor Model Application to Particulate Source Apportionment

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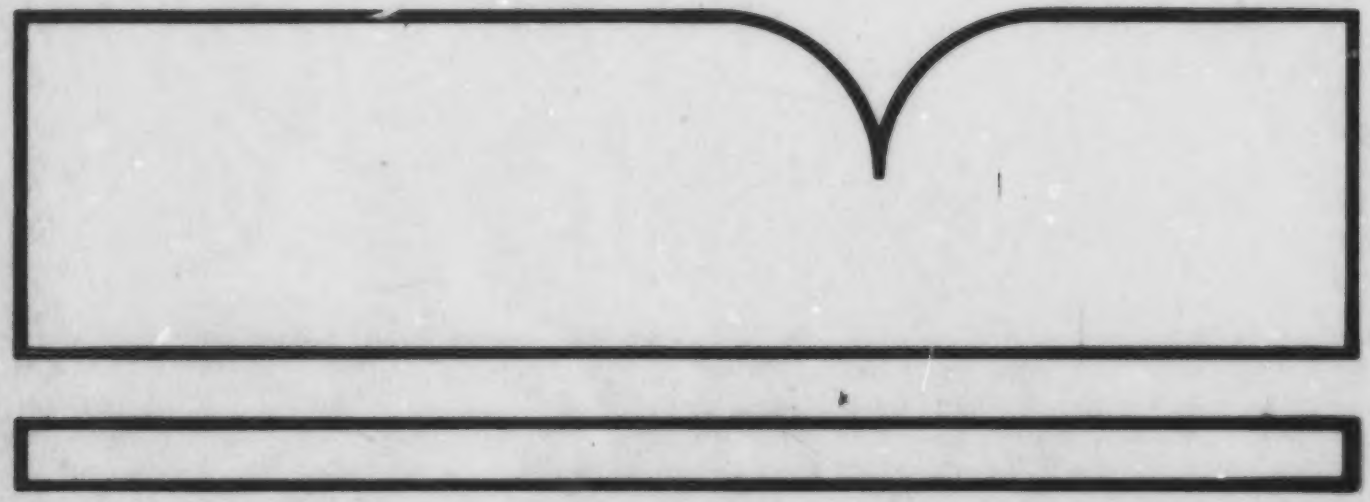

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July 1981

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Receptor Model Technical Series

Volume I

Overview of Receptor Model Application to Particulate Source Apportionment

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16. ABSTRACT

Volume I of the Receptor Model Technical Series presents an overview of current particulate source apportionment methods and their applications to control strategy development programs. It is the first in a series of documents describing methods which can be used to identify source impacts, using data collected at the receptor. This is unlike source (dispersion) models that estimate source strengths based on emission factors, plume behavior and meteorology. Volume II of the series describes the Chemical Mass Balance Receptor Model in detail. Future volumes will describe other receptor model techniques.

Information presented in this series is directed to regulatory professionals responsible for particulate control strategy development or related programs requiring source apportionment analysis. Major receptor methods are discussed, applications to control strategy development are presented and areas in which receptor models compliment source (dispersion) models are explored.

Properly applied, and with supportive evidence developed through independent approaches, receptor models can be used independently or in concert with dispersion models, to provide important new information to regulatory agencies.

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Receptor Model Technical Series

Volume I
Overview of Receptor Model
Application to Particulate Source Apportionment

Monitoring and Data Analysis Division
Office of Air Quality Planning and Standards

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

July 1981

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ABSTRACT

Receptor Model Technical Series

Volume I

Overview of Receptor Model

Applications to Particulate Source Apportionment

Volume I of the Receptor Model Technical Series presents an overview of current particulate source apportionment methods and their applications to control strategy development programs. It is the first in a series of documents describing methods which can be used to identify source impacts, using data collected at the receptor. This is unlike source (dispersion) models that estimate source impacts based on emission factors, plume behavior and meteorology. Volume II of the series describes the Chemical Mass Balance Receptor Model in detail. Future volumes will describe other receptor model techniques.

Information presented in this series is directed to regulatory professionals responsible for particulate control strategy development or related programs requiring source apportionment analysis. Major receptor methods are discussed, applications to control strategy development are presented and areas in which receptor models compliment source (dispersion) models are explored.

Properly applied, and with supportive evidence developed through independent approaches, receptor models can be used independently or in concert with dispersion models, to provide important new information to regulatory agencies.

EXECUTIVE SUMMARY

Air pollution professionals responsible for the development of air particulate control strategies and other particle impact analysis programs, have long been faced with the basic need to understand the relative importance of specific source impacts within their airsheds. Control officers responsible for developing particulate attainment strategies must be able to provide convincing evidence that (a) the relative importance of emission sources is understood and that (b) the control programs proposed are cost effective and can be adopted by the community with confidence.

Until quite recently, traditional approaches to the problem of apportioning source impacts have been limited to dispersion, or source, models which use emission inventory data (gathered at the emission source) with meteorological data to estimate impacts at the receptor. Unlike source models, receptor models deduce source impacts based on ambient particulate morphology, chemistry and variability information collected at the receptor. The increased interest in receptor models has resulted from the inability of dispersion models to assess short-term source impacts or identify sources which collectively account for all of the measured mass. These shortcomings are largely the result of the difficulty in developing accurate 24-hour particulate inventories and meteorological data bases.

In spite of their limitations, dispersion models will remain as an important tool in the regulatory effort since they are the only means through which particulate impact assessments can be made for proposed, new sources or at locations without measured data. Projections of future air quality and control strategy scenario analysis also require dispersion model approaches. Many receptor models

are also limited in their ability to identify specific sources (e.g., paved road dust) from among a group of chemically similar sources, such as soil dust, rock crusher emissions or building demolition dust. They do, however, provide information on the entire aerosol mass, not just those sources within the airshed. Used properly, however, receptor models can provide important insights into the nature of a community's particulate problem. Used in association with dispersion models, receptor-oriented techniques can be used to improve the performance of dispersion models and add confidence to the ability of the dispersion model to simulate impacts from specific sources.

The purpose of this document is to provide a brief overview of current receptor models, their application, advantages and disadvantages. Subsequent Volumes in this series will discuss the individual models in greater detail. The information in this document is directed to local, State and Federal air pollution regulatory professionals responsible for assessing the impact of particulate sources or in developing and evaluating State implementation plans. Others interested in the origin of ambient aerosols and in improving confidence in particulate dispersion model results will also find this information of interest.

Receptor models discussed herein can be placed in one of the eight categories, each of which is described below:

Chemical Mass Balance

This method matches source particle size and chemical "fingerprints" to those measured at the receptor to back-calculate the impact of specific sources or source classes of similar chemical composition. Given data on the ambient concentrations of several chemical species and the percent by weight of these

species in the emissions from the sources, a set of equations is prepared and solved to determine the source impacts.

Enrichment Factors

Ambient aerosol composition data are used in association with a reference element (usually a crustal element such as Fe, Al or Si) to provide an estimate of the degree to which a specific ambient aerosol element has been "enriched" by an anthropogenic source. If the "enriched" element is known to be a unique tracer for a specific source, and the concentration of the tracer in the source emissions is known, a crude estimate of the source's impact can be made.

Microscopic Techniques

Particle identification by optical microscopy was one of the first, and the most widely used method of source apportionment of coarse mode particles. Current technology has been expanded to include computer-driven scanning electron microscopy coupled with x-ray fluorescence analysis to provide a particle-by-particle analysis of ambient coarse particulate filters. As a consequence, particle identification methods traditionally founded on particle size shape, color, bifringence, and surface properties has been expanded to include elemental composition and rapid, computer assisted analysis permitting large numbers of particles to be analyzed at minimum cost.

Multivariate Methods

Statistical methods include factor analysis, regression methods, principal component and cluster analysis techniques. These methods deduce information on source impacts on the basis of the variability of chemical species measured within a large set of particulate samples. Given the premise that chemical

species emitted from a specific source will vary in time (as measured at the receptor) in the same manner, multivariate methods detect the common variability of the chemical species. The analyst then identifies the contributing source by comparing those species with similar variability to the chemical composition of sources within the airshed.

Radioisotope Analysis

Measurement of carbon-14/total carbon ratios have recently been used to distinguish "modern" from fossil fuel carbon. Using this method, carbon emitted from contemporary sources (wood burning, fireplaces, leaf fragments) has been distinguished from particles released by the combustion of fossil fuels, e.g., auto and diesel exhaust, coal and fuel oil carbonaceous aerosols.

Spatial Series Analysis

Spatial relationships between aerosol chemistry measured at numerous receptors can provide important clues to likely contributing sources when viewed in relation to emission density maps and given a basic understanding of the chemical composition of source emissions.

Time Series Analysis

Qualitative indications of source impacts based on temporal variations in aerosol mass and chemistry can be used, in association with source emission activity and transport data, to gain insight into likely source impacts over time.

X-Ray Diffraction (XRD)

Quantitative identification of crystalline substances in the coarse mode (>2.5 μm) by XRD has enabled analysts to determine impacts from fugitive emission

sources with reasonable accuracy (±25%) for moderate to heavily loaded filters.

Each of these methods has its own associated advantages and disadvantages. While no single technique is best used in all situations, two or more receptor models are often used in association with one another (or dispersion models) to provide increased confidence in program results. Hybrid models, which combine the best elements of two or more receptor or source-oriented models frequently offer the best approach to identifying source impacts.

Rather than viewing receptor models as a group of mathematical or analytical techniques, the analyst should recognize that the success of a receptor model study is highly dependent upon the adequacy of the air sampling, analytical, source characterization and data interpretation programs. Project management and quality assurance tasks are also important elements. The overall source apportionment program design, of which the receptor model is only one part, should therefore be of prime importance to those considering such a study. Analytical and air sampling techniques are inexorably linked to the receptor model to be used.

Size resolution of the ambient (and source emissions) aerosol into fine (<2.5μm) and coarse (2.5-10 μm) modes provides a simple, yet highly effective means of apportioning particles associated with combustion sources, secondary aerosols and controlled emission process losses from fugitive dusts and grinding and crushing operations. Commercially available sampling equipment typically collects the aerosol on inert filter substrates that are compatible with most of the analysis techniques used in receptor model studies.

Typical program costs can range from a few thousand dollars for a one year study of TSP source impacts at a single location to one hundred thousand dollars for a four station program designed to include fine and coarse mode analysis. More costly programs may be required in those situations which program results will heavily impact the communities.

Receptor models, principally optical microscopy, have been widely applied to particle source identification studies within the past 10 years. Studies associated with control strategy development programs, demonstration control strategy analysis, dispersion model validation, PSD and "bubble" analysis programs are typical. In each case, the user must select the most appropriate receptor (or source) model(s) and program design to provide the level of confidence needed to support the regulatory action required. In the case of control strategy development programs, receptor models can be used in association with dispersion models to (a) identify inconsistencies among source impact estimates derived from each method, (b) alert the analyst to emission inventory and dispersion modeling assumption errors, and (c) lend confidence to the dispersions model's ability to reasonably predict the impact of specific sources targeted for control.

Receptor-oriented methods of particulate source apportionment have evolved in recent years into a new air pollution science which is distinctly different than dispersion modeling. Several of these methods have demonstrated their ability to quantitatively identify source impact, often in situations which are not amenable to dispersion modeling. Total, fine, coarse and inhalable particulate fractions have been studied using these methods. Properly applied and with sufficient supportive evidence, receptor models can provide an important new tool to regulatory agencies.

ACKNOWLEDGEMENTS

The rapid growth in receptor model technology has been accomplished through the efforts of many researchers and regulatory professionals. While the current technology of receptor modeling is still in an early stage of development, those associated with its development see these methods as a tool of growing importance and potential to regulatory agencies.

The principal author of this document is John E. Core of the Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. The comments and assistance of those involved in the development of receptor models, as well as the Control Programs Development Staff, and Neil Berg, Jr., of OAQPS were important to the preparation of this document.

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1.0 INTRODUCTION

The Clean Air Act, as amended in August 1977, requires States to develop and implement State Implementation Plans (SIPs) designed to bring their airsheds into compliance with National Ambient Air Quality Standards (NAAQS). Faced with limited airshed capacity, emission growth, public concern and regulatory requirements, many communities are confronted with the difficult task of determining which particulate emission sources are contributing to these nonattainment problems and what the relative source impacts are. Although traditional techniques using dispersion modeling for source impact apportionment will remain an important tool in airshed management, recent advances in receptor oriented techniques are now beginning to offer an additional useful tool. Receptor models (techniques that estimate the contributions of emission sources based on data obtained at the receptor) include a variety of methods, each of which are briefly discussed in Chapter 2 of this document. In-depth discussion of these methods will be published as subsequent volumes in this series. Volume II (EPA-450/4-81-016b) describes the Chemical Mass Balance Method.

In the early phases of most control programs, point and area sources that were major contributors within the nation's particulate nonattainment areas were obvious and regulatory programs focused on emission reductions from these sources. Today, however, many communities that have seen benefits from the first and even second rounds of control still face continuing particulate nonattainment problems from aerosols of unknown origin despite the high level of control applied to many point sources. It is in the latter case that an improved understanding of source contributions are especially needed if cost-effective emission reductions are to be achieved.

The importance of an accurate assessment of source contributions during development of strategies is hard to overemphasize considering the cost of control. An appropriate example is that of a small, western nonattainment area located in a confined river valley surrounded by actively cultivated agricultural land. A large industrial point source located within the valley was believed to be the largest source contribution based on an emission inventory rollback model analysis. Construction of a new bag house to meet the required emission level was estimated to cost nearly $3 million. A more comprehensive source apportionment study using receptor methods, however, identified uninventoried soil dust as the major contributing source and estimated the annual geometric mean impact of the point source at less than 1.0 $\mu g/m^3$. Had the point source controls been installed, the industry's impact, as estimated by the source apportionment study, would have decreased by about 0.3 $\mu g/m^3$, reducing the measured TSP annual mean from 100 to 99.7 $\mu g/m^3$, for an overall cost benefit of $10 million per $\mu g/m^3$ reduction.

Results from source apportionment studies in Portland, Oregon, have shown cost benefit control alternatives to range from an overall cost savings per $\mu g/m^3$ to as high as $4.2 million per $\mu g/m^3$. While the cost benefits of alternative strategies will vary widely between communities, it is clear that considering the costs, health implications and the importance of implementing a successful regulatory program, accurate and comprehensive source apportionment studies are critical to the completion of State Implementation Plan revisions.

Faced with the need to identify and quantify contributions of different source categories to airshed particulate problems, air pollution agencies have, in the past, turned to traditional emission inventory and dispersion modeling

approaches to provide valuable clues to the likely point of origin of the particle mass. Other information, however, exists which can be used to identify the origin of particles:

- particle size, shape, color density or optical properties
- chemical composition (organic and inorganic)
- radioisotope chemistry
- particle size distribution
- concentration variability with space, time and meteorology

Because of the limited ability of some of the above characteristics to provide quantitative estimates of source impacts, there has been increasing interest in the development of receptor models. A receptor model is one which estimates source contributions given ambient observations made at the sampling, or receptor, site. The growth in receptor model technology has followed the development of rapid, low cost multi-element analytical techniques which provide extensive "fingerprint" information on the ambient aerosol. With accurate ambient aerosol "fingerprints" at hand, receptor models provide the keys necessary to draw inferences as to which sources, or source categories, contribute to the observed ambient aerosol mass.[1,2]

Determining the sources of airborne particulate matter is a very difficult problem because of the complexity of urban source mix. The problem is often confounded by the predominance of nonducted and widely distributed area (fugitive) sources and the lack of understanding of the sources of secondary aerosol, their formation and transport. The advent of receptor methodology and recent developments in the areas of trace element analysis now permit a much more detailed analysis of ambient aerosol samples. By providing detailed information on the

sources of the total, fine and inhalable particles, receptor models will likely play a major role during the development of strategies for controlling airborne particulate matter.

As promising as receptor models are, they cannot be applied to problems in which (a) the source does not exist (e.g., proposed new stationary sources), (b) impact increases associated with changes in stack dispersion parameters (plume temperature, volume or height), (c) identification of sources with chemically nondistinct emissions is needed, or (d) identification of sources contributing to secondary particulates (e.g., sulfates) that often dominate the fine particle mass is necessary.[3] Receptor models can be used to forecast future source impacts or to analyze alternative control scenarios if no changes in plume buoyancy, spatial or temporal characteristics of the emissions are assumed. For these reasons, receptor models cannot replace dispersion models. They can, however, be applied to situations not conducive to dispersion models analysis. Identification of source impacts during actual, short term particulate episodes, discovery of "new" uninventoried sources within the airshed and source apportionment of the background, as well as urban aerosol are a few of the most important advantages offered by receptor models.

Air pollution programs have traditionally used source oriented (dispersion) models to estimate the impact of emission sources in their airsheds. While numerous dispersion models (Gaussian, box models, conservation of mass grid models, particle-in-cell, etc.) have been developed, all require emission inventory, meteorological and dispersion parameter data to provide predictions of the ambient particulate concentrations. All of the source oriented models suffer

from an inherent inability to provide estimates of the source contributions to the aerosol mass transported into urban areas. Dispersion models cannot, therefore, provide a complete apportionment of the total mass of particulate measured within urban nonattainment areas.

Perhaps the most important deficiency of the dispersion modeling approach to source apportionment is in the accuracy and lack of completeness of the emission inventories used in the models. Complete fugitive dust inventories are extremely difficult to develop, considering the importance of transient sources, such as building demolition, road maintenance and construction. Source operating schedules are often not accurately known, emission factors are imprecise and those sources that are not inventoried are simply excluded from the analysis. Dispersion models are further limited by our ability to develop accurate regional emission inventories for input to models used to estimate source impacts during episodes in which the 24-hour particulate NAAQS is violated. As imperfect as dispersion models are, however, they remain a key element in control strategy development because they are the only mechanism through which the air quality benefits of alternative emission control programs can be evaluated, potential new source impacts can be assessed and future particulate air quality predictions can be prepared. Table 1 lists several particulate impact assessment scenarios commonly encountered by regulatory authorities. Those situations most appropriate to source (dispersion) and receptor modeling are listed. The analysts selection of the most appropriate model, or mix of source apportionment methods, will depend upon the specific problem and resources at hand.

The objective of this guideline is to provide those responsible for control strategy development with a better understanding of (a) the limitations and advantages of receptor models, (b) how receptor models can be applied to practical problems of source impact identification, (c) their use in control strategy development, and (d) the use of these techniques to compliment information gained from other methods. Since the most complete and accurate understanding of the source contributions will likely come from the application of several source apportionment techniques, no single receptor method should be used to the exclusion of other information. Experience has shown that as many different independent approaches as possible should be used in source apportionment studies to ensure that complete, valid conclusions can be drawn.

Table 1

Particulate Matter Impact Assessment Scenarios:
Source and Receptor Model Applications

Source (Dispersion) Models	Receptor Models
- Predictions of future air quality	- Fugitive emission impacts
- Analysis of alternative control strategies	- Analysis of actual, worst case 24-hour impacts
- Identification of secondary aerosol sources	- Identification of new, uninventoried sources
- Impact predictions associated with changes in stack height, temperature or volume	- Complex terrain/meteorology unsuitable for dispersion modeling
- Identification of impacts from one specific source from a group of sources, all with similar emission characteristics	- Impact analysis of sources with unique emission chemistry, morphology or variability
	- Whenever source apportionment must be independent of emission inventory and meteorology.

2.0 OVERVIEW OF SOURCE APPORTIONMENT METHODS

Receptor models are one of several source apportionment methods used to identify source contributions to the ambient levels of particulate mass. Although receptor models have been investigated as a method of source apportionment over the past ten years, only recently have the techniques been recognized as a distinct discipline and, in some applications, as an alternative and supplement to dispersion modeling. Dispersion models rely on measurements of emission rates, stack parameters and meteorology to estimate impacts. Hence, dispersion models are source-oriented models. In contrast, receptor models use actual ambient aerosol measurements to identify source contributions. Figure 1 illustrates the relationship between source and receptor models.

Since the urban atmosphere contains a complex and varied mixture of both organic compounds and inorganic compounds emitted by natural and anthropogenic sources, receptor models must sort out source emissions using combinations of properties that are uniquely associated with each source. Aerosol chemical composition, particle size, concentration variability and particle morphology are the four most important parameters used in receptor modeling. Unfortunately, each source's unique combination of "fingerprints" are often superimposed on one another such that no single source can be easily identified and quantified. The receptor model's task is to separate the "fingerprints," often using source emission composition information as a point of comparison.

Receptor models are typically classified as microscopic, physical or chemical methods, with each class subdivided into one or more specific areas of technology. Figure 2 shows the relationship among these disciplines. As the technology develops, the distinction between these three classes becomes less distinct, as

FIGURE 1

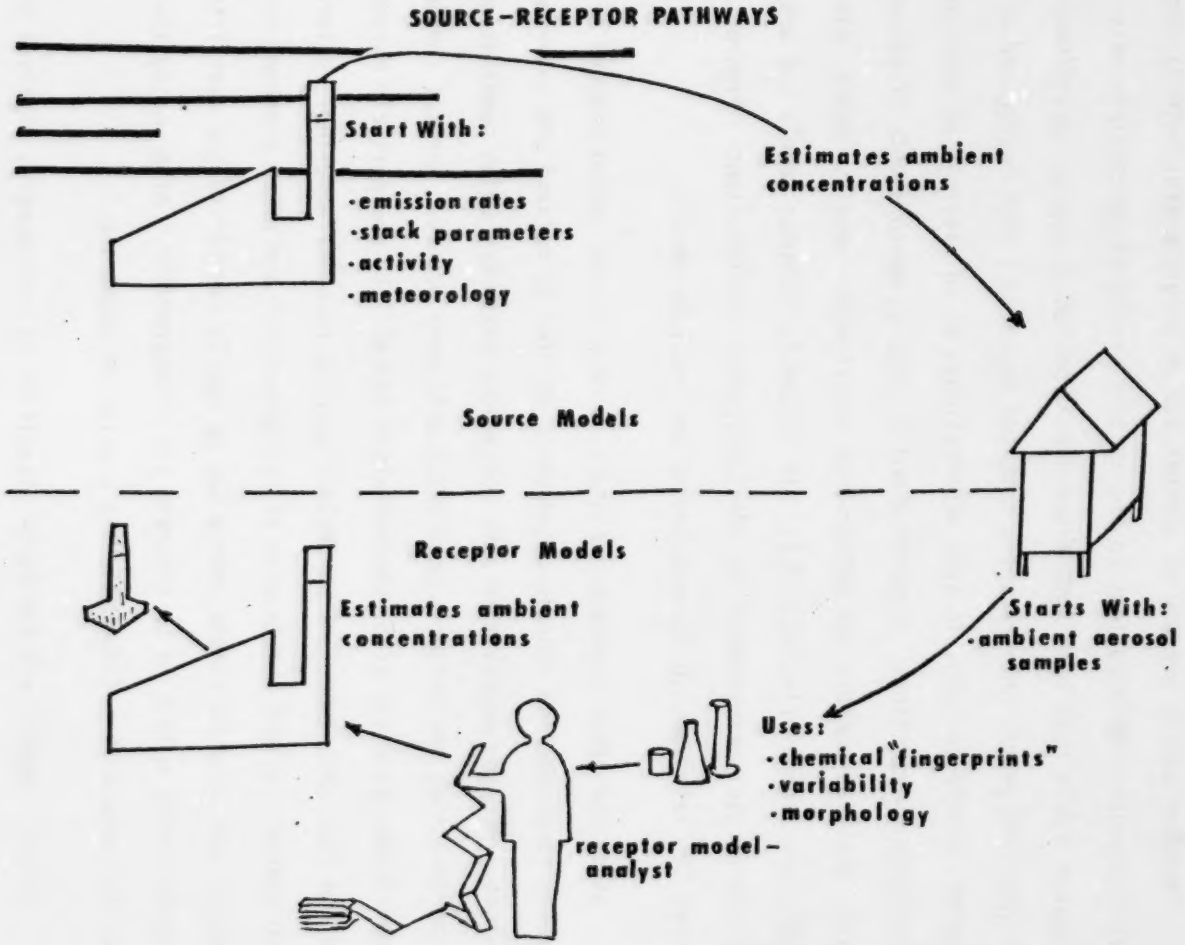
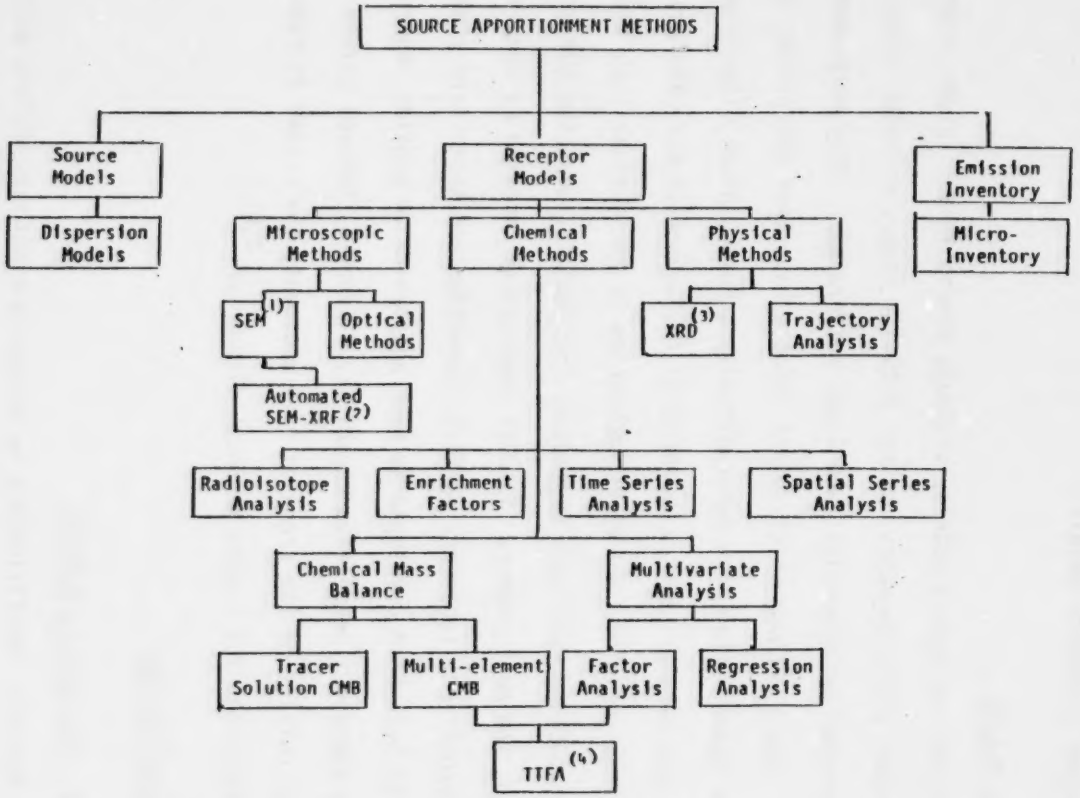

SOURCE-RECEPTOR PATHWAYS
Start With:
·emission rates
·stack parameters
·activity
·meteorology
Estimates ambient concentrations
Source Models
Receptor Models
Estimates ambient concentrations
Starts With:
·ambient aerosol samples
Uses:
·chemical "fingerprints"
·variability
·morphology
receptor model-analyst

Figure 2.



(1) Scanning Electron Microscopy

(2) X-Ray Fluorescence

(3) X-Ray Diffraction

(4) Target Transformation Factor Analysis

in the case of computer assisted scanning electron microscopy x-ray fluorescence (SEM-XRF) methods which classify individual particles by physical shape and elemental composition. Table 2 lists several source apportionment methods with their relative advantages and disadvantages. Each of the major methods are reviewed below in greater detail.

2.1 Source Models

Dispersion, or source models, estimate source impacts given information on emission rates, plume buoyancy, source activity (e.g., emission rates, operating hours and production schedule), and local meteorology. They represent the traditional means through which source impacts have been identified in recent years. The models attempt to mathematically simulate plume dispersion in the atmosphere and aerosol physics downwind of the source to estimate source impacts at a specified receptor. Numerous approaches to the complexities involved in dispersion modeling have been suggested: box models, Gaussian and grid (numerical) models being the most common. Special constraints dictated by complex terrain, particle deposition, secondary particle formation and short-term predictive capabilities have been developed as have adaptation to provide regional and long-range transport predictive capability. Since a thorough review of source modeling is outside of the scope of this document, the reader is referred to other publications for a more thorough discussion.[4,5]

2.2 Receptor Models

2.2.1 Microscopic Methods

Particle identification by microscopic methods include optical, scanning electron microscope (SEM) and automated SEM-Xray fluorescence (XRF)

Table 2. Source Apportionment - Receptor Model Advantages and Disadvantages

Source Apportionment Tools	Techniques Advantages	Disadvantages
Microscopy		
Optical	Use of color, surface texture and optical properties for particle identification	Limited to particles >2 μm, semi-quantitative, highly dependent on operator skill
SEM	Can be used with particles <1 μm	Costly to use on large numbers of particles, not useful for amorphous species
Automated SEM-XRF	Classifies particles by size, shape and elemental composition. Analytical speed, ability to count large numbers of particles	Still in early stage of development. Costly. Not reliable for organics, coarse fraction only
Chemical		
Enrichment Factors	Provides evidence of a source's impact by changes in aerosol composition. Simple	Semi-quantitative method; requires source composition data. Often not specific
Time Series Analysis	Provides clues to sources; simple, inexpensive	Generally does not provide specific source impact information
Spatial Series Analysis	Provides clues to sources, simple, inexpensive	Does not provide source impact information
Chemical Mass Balance	Provides quantitative estimates based on real data. Impact uncertainties provided	Source composition data required; chemically non-descriptive sources cannot be identified
Multivariate Analysis	No prior knowledge of sources needed to resolve element patterns, compositon required to identify sources by common names	Large data sets required, cannot provide short-apportionment
Radioisotope Analysis	Direct, quantitative measure of fossil carbon	Costly. Limited to fossil-"modern" carbon apportionment
Physical		
X-Ray Diffraction	Direct quantifaction of crystalline particles	Coarse particles only. Not useful for amorphous aerosols
Other		
Dispersion Modeling	Estimates impact from future and hypothetical sources	Difficulty in preparing accurate emission inventory and transport input data
Trajectory Analysis	Helps identify approximate source location	Cannot quantitatively estimate specific source impacts
Emission Inventory	Traditional method of source contribution analysis. Simple to use	Fugitive sources impossible to inventory, background aerosol not known; source impacts incorrectly assumed to be proportional to emissions
Microinventory	Qualitative estimate of nearby fugitive dust and point source impacts	Does not provide specific source short term periods

methods. These general groupings include specialized techniques, such as the use of polarized light optical techniques. Optical microscopy was one of the first widely used methods of particle identification and remains a valuable tool to qualitatively identify morphologically unique particles larger than about 2 μm. Particle identification is based on particle size, shape, color, and other characteristics, often with reference to a "library" of particles from known emission sources. In the case of optical microscopy, particle color and optical properties alone can often be used to assign particles to specific sources based on the operator's experience, extent of his particle reference library and associations with other particles found in the sample. Optical microscopy methods are limited by their relatively poor precision among analysts and the high cost associated with analyzing a sufficiently large number of particles to adequately represent the entire population of particles collected on a filter.

Although optical techniques are limited to particles greater than 1-2 μm, electron microscopy can be used to identify particles in smaller sizes using particle-by-particle analysis methods automated by computer. Individual particle identification by SEM is being supplemented with elemental analysis using energy dispersive x-ray fluorescence analysis. Once particle morphology, elemental composition and density data from numerous "reference" sources are developed, the SEM-XRF methods automated by computer can allow the research to scan the large number of particles required to conduct a representative analysis of the sample. While automated SEM-XRF methods appear promising, current technology is limited by the XRF sensitivity to particles greater than 1 μm in diameter. Analytical costs are also relatively high. Recent advances in this technique have, for the first time, successfully differentiated between coal fly

ash components and the lithophillic (crustal) particulate fraction captured on coarse mode dichotomous filters.

Table 3 lists typical source categories identified by the current SEM-XRF methods.[6] Note that although the mass less than 2 μm is estimated to be quite low, gravimetric analysis of the filters showed a significant fine particle mass model. This technology is quite new, however, and more research and method development is needed before wide-spread application of the method becomes possible.

2.2.2 Chemical Methods

Chemical methods of receptor modeling are the most recent approach to particulate mass source apportionment. Many different methods have evolved from different origins and are often perceived as distinctly different models when, in many cases, their only differences are in terminology and approach.

Chemical methods, in general, identify sources by comparing ambient chemical patterns or fingerprints (inter-elemental patterns, spatial or time variant patterns) with source chemical patterns. Source contributions are quantified by a least squares multiple regression analysis on either the particulate mass on different filters or the mass of individual chemical species on a single filter. Although similarities in the different chemical approaches are greater than their differences, they have been historically divided into two categories: (a) chemical mass balance methods, which attempt to define the most probable linear combination of sources to explain the chemical pattern on a single filter, and (b) multivariate methods, which attempt to define the most probable linear combination of sources to explain either the time or spatial variability in ambient chemical patterns.[7]

Table 3

Typical Automated SEM-XRF Analysis

Coarse Particle Fraction Source Apportioment
Average of Ten Samples - Durham, NC

(Weight % of Total Sample and Average Particle Diameter*, µm)

Chemical Category	<1.0 µm	1-2 µm	2-4 µm	4-8 µm	8-16 µm	>16 µm	Total
Low Counts (1)	0.0	0.0	0.13	0.27	0.15	0.0	0.55
Marine Aerosol	0.0	0.0	0.08	0.27	0.26	0.07	0.68
Ca and S Particles	0.0	0.0	0.10	0.21	0.0	0.16	0.47
Wood Combustion (2)	0.0	0.0	0.02	0.07	0.13	0.0	0.22
Refuse Combustion	0.0	0.0	0.03	0.10	0.10	0.0	0.22
Auto Exhaust	0.0	0.01	0.60	1.56	0.95	0.73	3.85
Fuel Oil Combustion	0.0	0.0	0.01	0.01	0.0	0.0	0.02
Coal Fly Ash	0.01	0.07	4.36	19.53	24.07	9.64	57.67
Industrial Combustion (3)	0.0	0.0	0.11	0.39	0.17	0.0	0.67
Dolomite (4)	0.0	0.0	0.03	0.03	0.0	0.0	0.06
Limestone (4)	0.0	0.0	0.08	0.31	0.13	0.0	0.53
Construction (4)	0.0	0.0	0.13	0.42	0.11	0.0	0.66
Asbestos/Talc	0.0	0.0	0.12	0.31	0.20	0.12	0.75
Illite (4)	0.0	0.11	0.72	2.20	2.08	0.64	5.75
Kaolinite (4)	0.0	0.01	0.60	1.20	0.97	0.19	2.97
Feldspar (4)	0.0	0.0	0.06	0.06	0.06	0.08	0.26
Mica (Biotite) (4)	0.0	0.0	0.04	0.09	0.02	0.10	0.25
Mica (Muscovite) (4)	0.0	0.01	0.28	1.33	1.14	0.25	3.01
Al Rich Particles	0.0	0.0	0.05	0.07	0.08	0.0	0.20
Si Rich Particles	0.0	0.02	0.66	1.83	1.18	0.06	3.76
Lithophilic (4)	0.0	0.06	2.52	7.81	5.28	0.56	16.23
Other	0.0	0.0	0.27	0.50	0.43	0.05	1.25
	0.01	0.29	11.00	38.57	37.51	12.65	100.02

Note:

1) Amorphous Compounds
2) Charred Wood Fiber
3) Combustion Sources Other Than Process Emissions
4) Usually Associated With Fugitive Dust Sources (e.g., Soils)

* Aerodynamic diameter

SOURCE: D. L. Johnson (Reference 6)

Radioisotope Analysis

Measurements of radioisotope carbon-14/carbon-12 ratios have recently been used by Currie and Klouda (National Bureau of Standards) and Cooper (Oregon Graduate Center) to distinguish between "modern" and fossil fuel derived carbonaceous aerosols.[8] The ability of radiocarbon measurements to resolve fossil from "modern" carbon is based on the fact that the isotopic ratio of $^{14}C/^{12}C$ in plant and animal tissue is in equilibrium with the same ratio in atmospheric CO_2, whereas fossil carbon contains essentially no radiocarbon (^{14}C) because of its old age compared to the half life of the ^{14}C isotope (5730 years). Consequently, carbon-14 is a unique tracer of carbonaceous aerosols emitted from contemporary sources (such as woodburning) and can be used to apportion the total carbon content of the aerosol into two distinct classifications. Limitations include the inability of the method to identify the specific carbon source, the high cost of analysis and analytical requirements for at least 5 milligrams of carbon (e.g., 50 $\mu g/m^3$ of carbon, 24-hour average at 60 liters per minute) to obtain 10-20% precision in the analysis. Source activity information on transport, coupled with size resolved samples, have been used to limit the number of possible emission sources.

As the carbon-14 analytical method is improved, the speed, cost and precision of the method will likely improve to the point where this tool may become available for analysis of large numbers of samples. Automated sample preparation equipment and low level radiocarbon counters could eventually process 10,000 samples per year at a cost of $200 to $400 per sample compared to current costs approaching $800 per sample (in groups of less than 4).

Enrichment Factor Models

The method uses ambient aerosol elemental composition data in association with a reference element to provide an estimate of the degree to which a given element has been "enriched" by an anthropogenic source.[9]

The generalized format for this application is:

$$EF_{(i)}\ \text{aerosol} = \frac{(C_i/C_{ER})\ \text{aerosol}}{(C_i/C_{ER})\ \text{reference}} \qquad (1)$$

Where $EF_{(i)}$ aerosol is the enrichment of the tracer element "i" in the aerosol, relative to some source material (usually crustal) and a reference element (usually Fe, Al, Si or Ca); C_i/C_{ER} is the ratio of the concentrations of tracer element (C_i) and the reference element (C_{ER}) in the aerosol and the reference material. The reference elements (C_{ER}) is often associated with crustal material because of (a) their abundance in ambient aerosol samples, and (b) referencing the element enrichment to a crustal (soil) source tends to minimize the effects of local meteorology on the enrichment factor $EF_{(i)}$. Factors close to 1.0 indicate that the reference material (or source of similar composition) is the primary source of the aerosol whereas factors significantly greater than 1.0 can normally be interpreted as resulting from the impact of other, anthropogenic sources.

The enrichment factor concept can be extended to provide a semi-quantitative estimate of source impacts if a unique elemental tracer can be assigned to a source and the weight percent concentration of the element in the source emission mass is known. In this case, the formula below is used:

$$C_s = \frac{(C_i/C_{ER}\ \text{Impact}) - (C_i/C_{ER}\ \text{No Impact})}{(C_i/C_{ER}\ \text{Impact})\ (F_{ij})} \quad x\ \bar{C}_i \qquad (2)$$

Where C_s is the source impact, in $\mu g/m^3$; C_i is the ambient concentration of the tracer element in $\mu g/m^3$; F_{ij} is the fraction of tracer element "i" in source "j" (weight %) and $\bar{C}_i$ is the mean ambient concentration of element "i" (C_i) ($\mu g/m^3$) during the study period. Used in this form, enrichment factor analysis is quite similar to a simple chemical mass balance model. For example, the investigator may be interested in determining the relative enrichment in the fine particulate potassium concentration (Ci) relative to the crustal reference element iron (C_{ER}) during periods of suspected source impact. Lyons[10] used fine particle potassium as a tracer for smoke from vegetative burning. The average $^{K}/_{Fe}$ ratio during smoke impact periods was found to be 2.0, compared to an average ratio of 0.6 during periods of no smoke impact. If the average fine particle potassium concentration found during the study was 0.2 $\mu g/m^3$ and the smoke is known to contain 6.0% by weight potassium, equation 1 can be used to estimate the average fine particle smoke impact: (C_s):

$$C_s = \frac{2.0 - 0.6}{(2.0)\ (.060)}\ x\ 0.2$$

$$C_s = 2.3\ \mu g/m^3$$

As useful and flexible as enrichment techniques are, they are only semi-quantitative at best. The method's best application is in identifying the presence of abnormal sources at rural or remote sites and in providing an elemental "index" relatively free of meteorological influence. By examining enrichment factors over time, and in relation to source activity and transport, inferences

can often be made as to the likely source of the tracer element. Since the technique is not applicable in situations in which multiple sources are emitting the same element, it will therefore not find wide application in source apportionment studies.

Time Series Analysis

These methods are based on the assumption that the chemical species emitted by a source will have the same time dependence at the receptor, resulting in a high degree of correlation between the species. To minimize meteorological effects, the species concentrations may be expressed as a percent of the aerosol mass or normalized in relation to another specie. Once highly correlated specie groups are identified, the contributing source can be inferred from (a) a qualitative understanding of the airshed source emissions and composition, and (b) the diurnal, weekly and seasonal trends in the data and source emissions. Long term trends in pollutant concentrations are one example of time series analysis.[11]

These methods are simple, yet provide strong evidence as to possible source influences. They do not, however, provide quantitative estimates of specific source impacts. Their principal use is in trend analysis to evaluate control strategy effectiveness and track air quality trends.

Spatial Series Analysis

The spatial relationships between aerosol mass and chemical species can provide important clues as to likely sources if a sufficiently dense network of sampling sites has been included in the project design.

Measured concentrations of the aerosol mass and/or specific chemical species from several sampling sites obtained for identical time periods can be examined in relationship to airshed emission points. Implications can then be made between the sources and spatial patterns, if some prior knowledge of the chemical nature of the emission composition is at hand. In some cases, in which a single element is unique to a source, this kind of simple analysis has qualitatively identified the presence of previously unknown sources or served to illustrate the geographical extent of a source's impact.

Other spatial models such as pollution rose and cluster analysis are useful, but rely on constant wind directions and emission rates to identify the contributing sources. These constraints severely limit the method's ability to identify specific sources.[9]

Chemical Mass Balance

The purpose of the chemical mass balance technique (also known as chemical element or chemical species balance) is to permit the investigator to use available ambient aerosol composition data (elemental, ion, carbon, etc.) in association with similar ambient aerosol data, to back-calculate the impact of specific source, and source classes at the receptor. The method essentially matches the source's particle size and chemical "fingerprint" to those measured at the receptor.

The CMB method is based on the assumption that the mass of the material deposited on a filter at the sampling site is a linear combination of the mass contributed from each of a number of sources and that the mass and chemical composition of source emissions are conserved from the time of emission to the

time the sample is taken. With these assumptions, it can be shown that the concentration of a given chemical specie measured on the ambient filter is equal to the sum of the same chemical specie contributed by each source. More specifically:

$$C_i = \Sigma F_{ij} S_j$$

where C_i = fraction of the measured aerosol mass, attributed to specie i, at the sampling site, dimensionless

F_{ij} = fraction of specie "i" in the emissions from source j (e.g., 2% of soil dust mass is Na), dimensionless

S_j = fraction of the aerosol mass collected at the sampler from source j (e.g., soil impact, expressed as a ratio to mass), dimensionless

Since C_i and F_{ij} can be measured by chemical analysis of ambient and source samples, the S_j source contribution can be determined mathematically by a least squares solution to a set of simultaneous equations.[12,13,14] Advantages and disadvantages of the CMB method are summarized in Table 4. Further detail on the CMB method is presented in Volume II of this series.[15]

Multivariate Methods

Statistical and multivariate methods include factor analysis, regression methods, target transformation factor analysis (TTFA), cluster and principal component analysis techniques, and other methods. These methods extract information about the source's contribution on the basis of the variability of chemical species concentrations measured within a large set of particulate samples. Given the premise that the chemical species concentrations measured at the receptor

Table 4. Chemical Mass Balance Advantages and Disadvantages

Advantages	Disadvantages
° Quantitative method	° Requires source composition data
° Can be applied to data from a single sample. Can use small data sets	° Cannot resolve sources of secondary aerosols
° Can be applied to data collected from short term sample ($\leq$24 hours)	° Typically unable to account for all measured Ca, Cu, Zn and carbon
° Provides an estimate of source impact uncertainty	° Assumes that all species emitted by a source, within a given size range, have the same residence time
° Internal consistency checks of analysis quality can be made	° Cannot distinguish sources of similar chemical composition
° Identifies sources/source classes by common name	

attributed to a specific source will all vary in time or space in the same manner, multivariate methods detect the common variability among the species. Source identity is then implied by comparing species of similar variability to the composition of specific sources. Although the methods require no prior knowledge of the number or composition of the source components to identify major source groupings, the correct labeling of the groupings or factors in terms of common source names does require a knowledge of the chemical composition of possible sources. Important advantage of these methods include:

° the ability to include non-chemical measurements, such as light scattering, gaseous pollutant measurements and meteorology in the data set;

° no prior assumptions regarding the number of sources impacting the receptor.

These advantages allow factor analysis methods to associate primary particles with secondary species formed between their release and measurement at the receptor. For example, secondary sulfate formed in the plume of a residual oil fired boiler could be identified by factor analysis based on similar variation of Ni and V (fuel oil trace elements) with sulfate. If the plume becomes sufficiently well dispersed downwind to become homogeneous, however, the association may not be detected.

Multivariate methods have been found effective in identifying sources of secondary aerosols, fugitive emissions, motor vehicle exhaust, soil, residual oil combustion and other source components. A recent review of receptor model technology[1] has summarized results from source apportionment studies using multivariate methods as follows:

° Hopke (University of Illinois) and co-workers applied factor analysis to 18 elements measured from a set of 90 total suspended particulate samples from Boston. Six source classes (factors) which collectively accounted for 77 percent of the system variability were identified. The three major components identified were a soil component possibly containing coal fly ash, marine aerosol, residual oil combustion.[16]

° Moyers and co-workers (University of Arizona) completed factor analysis of 24 elements from a TSP hi-vol network of 11 sites in Tucson, Arizona. The major impacts found were soil and secondary species such as ammonium and sulfate ion. Auto exhaust and mining related emissions were also found as was a marine aerosol component.[17]

° Lewis (EPA-ESRL) and Macias (Washington University) used factor analysis on fine and coarse mode dichotomous samples taken in Charleston, West Virginia in 1976. Nineteen elements were used to resolve the soil, ammonium sulfate and automotive components as well as an unknown component composed of C, N, Si, K, Ca, Fe, Zn, Se and Sr. No coal fly ash component was found despite its importance as a source in the airshed.[18]

As helpful as multivariate methods are in source resolution studies, factor analysis methods have several weaknesses. Very strong, consistent source impacts which co-exist amidst weaker, more variable sources may not be identified because the method depends on source variability, rather than absolute values, to identify the source component. The methods do not provide information on the composition of the source components but indicate only the fraction of an element's variability associated with a given source.

Unlike factor analysis which apportions system variance, Target Transformation Factor Analysis (TTFA) permits an analyst to apportion aerosol mass in a manner similar in nature to the chemical mass balance method, but without the presumption as to the number or nature of the sources in the system. The method appears to hold promise as a useful tool, but will require additional testing before its full value to source apportionment analysis can be evaluated. Recent TTFA studies by D. Alpert and Hopke (University of Illinois) on St. Louis, Missouri size resolved aerosol data was completed using data for 27 elements.[19] The study identified fireworks smoke (detected in July 4th samples), motor vehicle exhaust, a soil coal fly ash component, limestone, paint pigments, refuse incineration and sulfate ion as contributing sources, the sum of which estimated the fine and coarse mass measured to within an average deviation of about 16 and 12 percent, respectively.

2.2.3 Physical Methods

X-Ray Diffraction

X-ray diffraction (XRD) has been successfully used by several investigators[20, 21] to quantitatively identify concentrations of crystalline substances in ambient samples. Road salt, lime, calcium carbonate, gypsum, cement dust and numerous crustal minerals (calcite quartz, biotite, etc.) associated with fugitive emissions have been successfully identified.

Recent work by Davis (South Dakota School of Mines) using dichotomous samplers with Teflon filters indicates that XRD analysis of ambient samples with high mass loadings (200 $\mu g/cm^2$ of filter area)* can be accomplished within an

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* Equivalent to 60 $\mu g/m^3$ at 15 lpm (24 hours) using a dichotomous sampler.

accuracy range of ± 25% for most components. Since crystalline components most suitable to XRD analyses are found primarily in the coarse particle fraction, the method's principal application has been in coarse particle source apportionment. X-ray diffraction cannot be used to measure non-crystalline aerosols (organics, acid aerosols, etc.). Moderately heavy filter loadings are usually required for analysis. New instruments now under development promise to greatly shorten current analysis time.

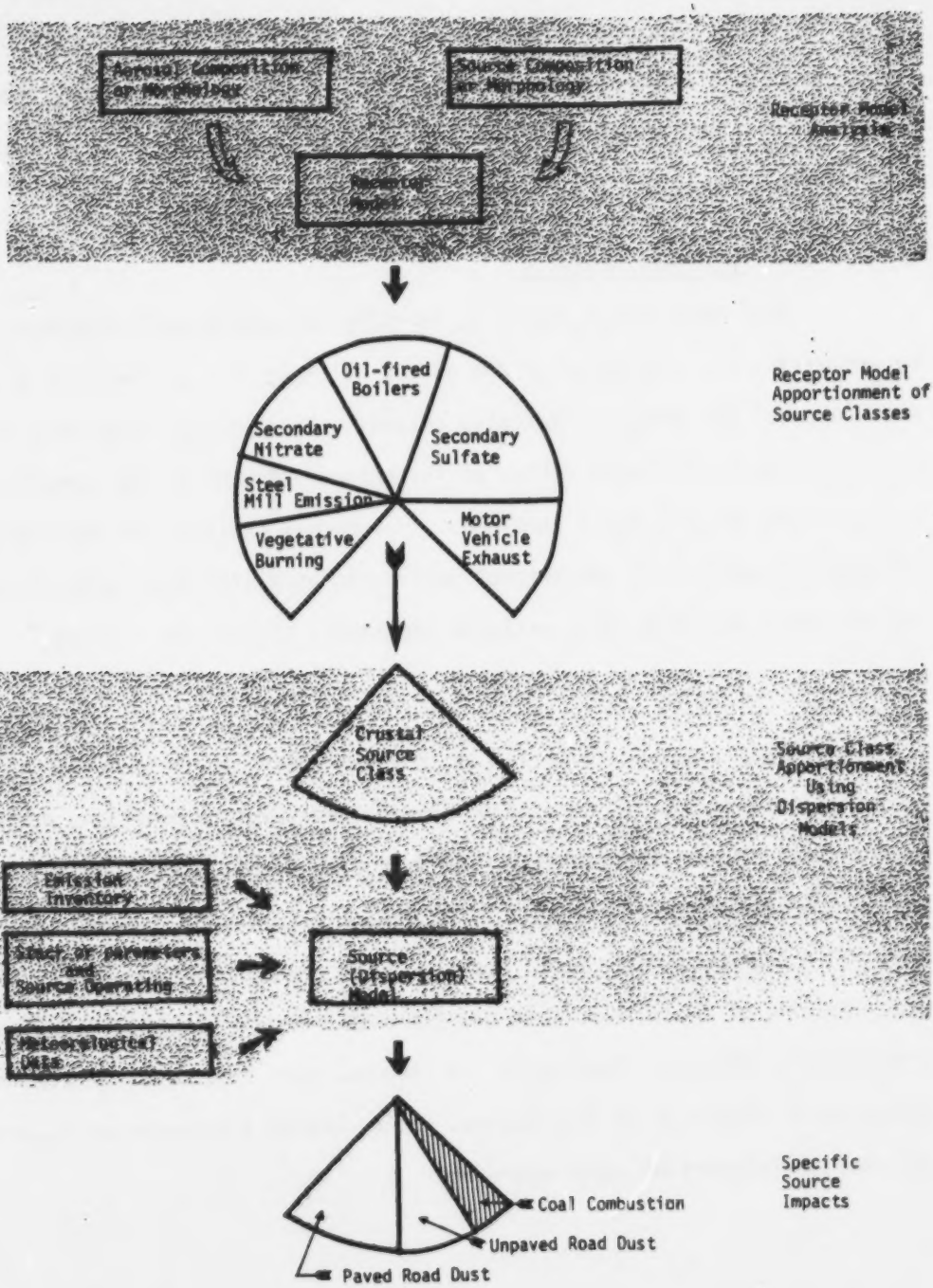
Trajectory Analysis

This technique attempts to identify the approximate origin of particles by recreating the trajectory of the air parcel sampled. In the case of 24-hour measurements, the analysis typically assumes only a single trajectory, arrival of the air parcel at the site either at the end or midpoint of the sampling period and transport of only small particles. Trajectory analysis has been used to estimate the portion of the aerosol mass associated with long range transport, but it cannot quantitatively estimate the impact of specific sources.[9]

2.2.4 Hybrid Models

Since a major limitation of receptor models is their inability to distinguish among sources of similar chemical/physical composition, hybrid models which combine the advantages of two or more receptor methods (or receptor and source models) have been seen as a promising approach. Figure 3 describes the hybrid source/receptor model process, using receptor models to calculate contributions of the source types and the source model to quantify contributions from specific sources. Application of chemical mass balance/dispersion model is discussed in Volume II of this series, while Chapter 4 presents an overview of the receptor/dispersion model approach.

Figure 3. Source-receptor Model Hybrids



After Watson (Reference 20)

The microinventory-regression approach developed by Pace[22] has been suggested as a useful method of apportioning chemically similar sources (e.g., soil dust, paved road dust, rock crusher emissions) identified by chemical mass balance or factor analysis. The current state of the art requires that the analyst conduct the microinventory-regression analysis as a separate task following completion of the receptor model work. No combined software package currently exists which joins the two methods.

2.3 Emission Inventory Methods

Airshed emission inventories were the basis of most first attempts to determine the relative contribution of specific sources to community particulate problems. Experience, however, has shown that this approach is confounded by numerous difficulties that severely limit the direct use of inventories for source apportionment. Perhaps the most important sources of error inherent in the required assumptions are that (a) the inventory accurately includes all sources affecting the receptor, (b) that the ratio of emission rates within the inventory is the same as the ratio of the source impacts, and (c) the method does not account for transported pollutants.

Emission inventory methods are, however, useful to identify major sources or source classes that may contribute to measured particulate matter concentrations. The inventory's value in source apportionment work is greatly enhanced if each source class is spatially resolved into grids of sufficient resolution (2 km x 2 km) to be useful in trajectory analysis. A spatially resolved fugitive dust inventory, when viewed in relation to a known dust source can often identify inventory deficiencies while providing guidance on needed improvements. As an example, application of a uniform paved road dust emission factor throughout a

community of mixed land uses may, when examined as gridded emission densities, conflict with "real world" impressions of the amount of street dust found in industrial as compared to residential areas. Correction of the deficiency may required use of land-use specific emission factors which, when included in the dispersion model data base, would greatly improve modeling results.

Emission inventory scaling techniques can occasionally be used in association with other source apportionment methods to identify the impact of an unknown source. If, for example, chemical mass balance methods can identify the impact from a residual oil-fired boiler located adjacent to a distillate oil-fired stack, the impact from the distillate fuel combustion emissions can reasonably be assumed to be in the same proportion as the emission rates of the two boilers if (a) the plume height and dispersion characteristics of both sources are similar, (b) the operating schedule for both sources is identical, and (c) the particle size distribution and deposition rates of the emission are the same.

This approach is occasionally used to identify the impact of diesel truck emissions. Given the impact from leaded automotive exhaust (often based on a Pb tracer) and the inventory ratio of diesel/leaded exhaust emission, the impact of diesel emissions can be calculated if the diesel and automotive emissions are assumed to be spatially and temporally similar. This may, or may not, be defensible based on the location of the sampling sites to nearby roadways and the local traffic mix.

Microinventory methods are procedures by which annual particulate matter emissions are estimated in relatively small areas surrounding the monitoring site.[22] Area sources are typically inventoried within a one-mile radius while

point sources within a five-mile radius are usually included. Inventories developed for each of nine sectors surrounding the site are then related to site TSP mass data by regression analysis techniques. While this method does not assist in aerosol characterization, it can qualitatively estimate relative fugitive dust and point source impacts by performing intersite comparison of emissions for sampling locations with similar particulate matter concentrations. Microinventory data can be used to produce a multivariable, empirically-based predictive equation or can be used with dispersion models to identify relative source impacts.

2.4 Selecting the Appropriate Technique

Selection of the most appropriate technique from those discussed above, will largely depend on the analyst's objectives, resources and the available technology. For the purposes of this Section, however, we will assume that the objective of the source apportionment program is to identify the sources contributing to inhalable particulate mass loading during actual air pollution episodes. Regardless of the intent of the analysis, it is highly important that the analyst:

1. Identify the nature of the problem and review information already on hand. Familiarity with the airshed's sources (magnitude, location, operating characteristics of sources, fuels and fugitive emissions), the chemical composition of the aerosol, it's size distribution, dispersion model results, and meteorology are of key importance.

2. Develop specific objectives, resources and the available time frame within which the analysis must be conducted. These restraints are often critical to the proper technique selection.

3. Insure that tasks included in the program design are consistent with the objectives, resources, sampling and analytical techniques to be used.

In the example case described above, dispersion modeling and microinventory methods are not likely to be helpful given the extreme difficulty in accurately assessing the emissions for a single day in history. Multivariate methods, which require large data sets, could only be used if the sampling program were designed to capture a large number of time-resolved samples from a large number of sampling sites. Time series analysis also requires data captured over long time periods.

The available options, listed in Table 5, provide the analyst with several choices of coarse and fine mode techniques which provide qualitative, semiquantitative or quantitative results depending on the analysis requirements and resources at hand. Methods 1 and 2 can provide semiquantitative data at less cost than method 7's (CMB) quantitative results, if it is assumed that no CMB source composition data are on hand. Considering the wide range of possible applications, no single technique can be considered the most effective.

Note that the relative resource requirement ratings in Table 5 are by necessity subjective. It is, however, clear that the resource requirements of methods 2, 3, 10 and 12 are beyond those available, on an in-house basis, to most agencies.

Each source apportionment tool has its unique strengths and limitations, and each can provide valuable insight into sources contributing to air particulate levels. The most cost effective tool or set of tools, however, will depend on the nature of the airshed, potential sources and the accuracy and precision of source apportionment required.

Table 5

Source Apportionment Technique Applications*

Method	Technique	Capabilities (1) Coarse Mode	Fine Mode	Application to Short Term Episodes	Resource Requirments (2) Manpower	Skill	Computer	Data
1	Optical microscopy	SQ	-	x	4	5	1	2
2	SEM microscopy	SQ	SQ	x	4	5	1	2
3	Automated SEM-XRF	Qn	-	x	5	5	3	2
4	Enrichment Factor	SQ	SQ	x	1	2	2	3
5	Time Series	QL	QL		1	2	2	3
6	Spatial series	QL	QL	x	1	2	2	3
7	Chemical Mass Balance	Qn	Qn	x	4	5	2	5
8	Multivariate methods	Qn	Qn		3	5	2	5
9	Dispersion modeling	Qn	Qn		2	4	3	5
10	X-ray diffraction	Qn	-	x	4	5	1	2
11	Microinventory	SQ	SQ		3	2	1	2
12	Radioisotope Analysis	Qn	Qn	x	5	5	1	2

* After Throgmorton and Axtell[9]
(1) Source apportionment capabilities:
SQ = semi-quantitative
QL = qualitative
Qn = quantitative
(2) Judged on a scale of 1 to 5, 5 being the most resource intensive

The results from a single interpretive approach may be insufficient to develop the level of confidence required in those cases where strong action is to be taken. Ultimately, the decision as to the likely adequacy of the analysis must be judged on a case by case basis by the program manager. The objective of source apportionment studies must be to build a strong enough bridge of circumstantial information to quantitatively relate a source to an impact. Thus, the entire information base must support, and be internally consistent with, the study's conclusions if decision makers are to have confidence that their actions will result in improved air quality.

3.0 PROGRAM DESIGN AND MANAGEMENT

The success of source apportionment programs is highly dependent upon the thoroughness with which the program is designed. Emphasis must be placed on a closely integrated approach which brings together the program objectives, field sampling program, analytical, quality assurance, data management, and data analysis tasks. Accomplishment of these tasks requires a well organized system for program management encompassing technical, fiscal, administrative, and community concerns.

As a first step in program design, specific objectives must be drafted and extensively discussed to ensure that the end result of the program provide useful information to the regulatory process. Following identification of specific program objectives, program constraints (time and resource considerations) important to program design must be known. A detailed survey of existing manpower, fiscal, equipment, and data resources should be completed to identify data gaps that need to be included in the program plan, equipment needs, personnel shortages and/or fiscal shortfalls. These shortcomings must be resolved at an early stage of the program planning process to insure that an overall, viable program can be implemented.

3.1 Experimental Design

There are four main phases of a source apportionment study: ambient sampling and analysis, program design, development of source composition data, and data interpretation. Each must be optimized to attain the highest level of source resolution and most accurate apportionment results.

3.1.1 Sampling and Analysis Design

The first phase, sampling, is as critical as the other two in contributing to the overall resolving power of a study. Sampling parameters which exert the greatest influence on source resolution include selection of ambient samplers, filter substrates, sampling frequency and sampling duration. These parameters, however, are not independent and their choice will represent a compromise between maximizing analytical sensitivity, precisely defining the variability of the source strengths and available resources.

Although the specific ambient sampling equipment used in the study will depend on the receptor model(s) to be used, a dichotomous sampler with a fine to coarse cut point of about 2 μm is usually preferred for use with chemical receptor models because of the bimodal nature of the ambient aerosol and its sources. Physical separation of the aerosol according to particle size is the first stage of source resolution since it divides the particles into two broad classes, separates the basic (coarse) particles from the acidic (fine) aerosol, and increases analytical sensitivity.

The filter material of choice for chemical and microscopic methods is a thin Teflon membrane, since it minimizes artifact formation, maximizes analytical sensitivity by X-ray fluorescence analysis and is compatible with microscopic analysis protocol. Although X-ray fluorescence (XRF) may not be the only analytical technique used, it is generally accepted as being the most cost effective analysis for chemical models. XRF analysis cannot, however, be used to obtain data on Na and other potentially valuable trace elements. Table 6 lists analytical techniques useful for ambient aerosol measurement. Filter surface density and blank filter trace element impurities are very low, thereby improving

Table 6. Analytical Techniques for Urban Aerosols

Method	Type of Sample	Quality	Elements Measurable	Major Limitations
XRF	Dichot. sampler, >2.5 μm	Good:	Al, Si, P, S, Cl, K, Ca, Ti, Mn, Fe, Cu, Zn, Br, Pb	No data on very light elements (e.g., C, N, H, O, Na) or on some very trace elements useful in source identification
		Marginal:	V, Ni, As, Se	
	<2.5 μm	Good:	Si, P, S, Cl, K, Ca, Fe, Cu, Zn, Se, Br, Pb	
		Marginal:	Al, Ti, V, Mn, Ni, As, Cd	
INAA	Filter or cascade impactor	Good:	Na, Mg, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Cu, Zn, As, Se, Br, Sb, I, Cs, Ba, La, Ce, Sm, Eu, Hf, Ta, Th	No elements below Na; misses Si, Pb totally; marginal for Ni, Cd. Long turn-around time (2-3 weeks) for complete analysis
		Marginal:	S, Ni, Ga, Rb, Sr, Ag, Cd, In, Yb, Lu, W	
Atomic absorption	Filter or cascade impactor	Good:	Li, Be, Na, Mg, K, Ca, Cr, Mn, Co, Ni, Cu, Rb, Sr, Cd, Cs, Hg, Pb, Bi	Have to dissolve samples; some inter-element interferences, but difficult to detect. Special methods needed for some elements (e.g., Hg).
		Marginal:	Al, Si, Ti, V, Fe, Zn	
Ion chromatograph	Filter or cascade impactor	Good:	SO_3^{2-}, SO_4^{2-}, NO_2^-, NO_3^-, F^-, Br^-, Cl^-, NH_4^+, Na^+, K^+	Have to dissolve samples. Special care needed to preserve unstable oxidation states

SOURCE: Controlling Airborne Particles (Reference 23)

analytical sensitivity. The analytical sensitivity of XRF for aerosols deposited on a stretched Teflon membrane with a density of about 0.3 to 0.4 milligrams per square centimeter (mg/cm^2), for example, is about three times greater than for an aerosol deposited on a cellulose based filter with a surface density of about 4 mg/cm^2.[7] This difference can be translated into either more information for the same analytical costs or the same information for a lower analysis cost.

Selection of sampling frequency and duration will be determined primarily by the relevant standard, potential sources and resources. Since the current particulate matter standards are based on a 24-hour and annual averages, sampling duration should probably not exceed 24 hours. Sampling for less than 24 hours will usually substantially improve the ability of receptor models to resolve source impacts because of the more precisely defined time dependence. Sampling for less than 24 hours, however, increases cost substantially and may not be necessary to achieve the objective of a program designed to provide an initial survey of source impacts.

The primary objective of the ambient aerosol chemical analysis step is to accurately measure the major chemical components and key indicating species (e.g., Pb for automotive exhaust, Ni and V for residual oil, Al and Si for road dust) for input to chemical receptor models. Although it is not essential that all of the major chemical species be measured, it greatly improves the credibility and confidence in the final results if most of the aerosol mass is explained. Carbon and silicon should be measured because they represent two of the most abundant chemical species present in a typical urban aerosol, and because they are useful source indicating elements. In general, Na, Mg, Al, S, K, Ca, Fe and Pb should be measured because of their abundance and their roles in source fitting.

Other elements such as P, Cl, Ti, V, Cr, Mn, Ni, Cu, Zn, Br, Rb, Sr, Zr, Cd, In, Sn, Ba, rare earths, etc., explain smaller portions of the total mass but may, nevertheless, be key indicating elements. Chemical species such as sulfate, ammonium and nitrate ions, as well as specific organic compounds, may also be useful. Table 7 lists chemical species that should preferably be measured in the fine and coarse mode ambient (and source) aerosol if chemical receptor models are to be used. Fewer species have been successfully used, however.

Table 7

Chemical Receptor Model Aerosol Analysis Requirements (size resolved samples preferred)

mass	Cl	Fe	Pb
Na	K	Ni	SO_4
Mg	Ca	Cu	NO_3
Al	V	Se	Organic Carbon*
			Elemental Carbon*
Si	Cr	Br	
S	Mn	Ba	
As	Sr	Cd	
Sn	Sb		

Sample analysis requirements of other receptor models, such as optical microscopy, X-ray diffraction or radioisotope methods, is an integral part of the technique itself, thereby largely bypassing the requirements described above.

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* Organic and elemental carbon are measured by volatilization of the sample at 650°C in a helium atmosphere to detect the organic carbon component followed by oxidation in a helium-oxygen atmosphere to measure the elemental carbon fraction. Measurement of these two components have proven useful in apportioning carbon sources (wood burning, diesel exhaust, etc.)[15]

Measurement of specific organic compounds should be undertaken only after a thorough review of the expected source, transport, and analysis chemistries has shown the candidate compounds to have reasonably constant production rate, a reasonable aerosol lifetime and ability to be measured by a relatively low cost analysis technique. The set of essential chemicals and preferred analytical techniques will be determined by the specific sources in each airshed. Selection of an optimum sampling and analysis protocol, based on a thorough understanding of the chemistry of potential sources, can result in substantial cost savings and greatly improved source resolution.

Important considerations influencing the success and cost of the program include:

° The Number and Location of Sampling Sites

Sampling location in "hot-spot" nonattainment areas, coupled with a similarly equipped site at a background location form the basis for most studies. Other locations in areas of potential industrial growth or in areas of differing land use may also be necessary to meet the program design requirements.

° Sampling Scheme

The sampling frequency may be based on a random schedule (usually patterned after the SLAMS/NAMS network schedule) or on synoptic meteorological conditions. Other schemes designed to collect data during air pollution episodes, periods of visibility impairment, specific plume transport conditions or periods of source activity may also be selected. Diurnal or weekend-weekday sampling schemes may occasionally prove useful in situations where the source under study exhibits major day/night or weekend emission changes. Regardless of

the scheme selected, however, the relationship between the collected data and the 24-hour worst case, seasonal or annual averaging periods are also likely to be of major interest.

° Sample Analysis Criteria

Since wholesale analysis of all of the samples collected during a study can be extremely costly, a set of sample analysis criteria are often developed as a basis upon which samples may be selected for chemical analysis. Whatever the criteria used, they must be consistent with the program objectives, resources and data analysis requirements. A basic criterion used in many studies, for example, is to conduct analysis of all samples which exceed the ambient air standard.

° Ambient Sampling Equipment

Sampling instrumentation is of key importance to the credibility and overall cost of most source apportionment studies. Selection of instrumentation must include many considerations: compatibility with analytical requirements, reliability, serviceability, automated filter change capability and power requirements to name a few.

° Analytical Methods

The analytical methods to be used are selected after the chemical specie to be measured, analytical precision and the detection limit requirements are known. The speed and cost of the analysis, data handling, and personnel requirements and quality assurance aspects all have a major impact on the program cost.

° Data Management

Systems for data capture, entry and merging are often required to manage the large volume of data generated during chemical receptor model studies. Because of the large volume of data generated and the tendency to minimize the importance of data management, these tasks often become the single, most complex and time consuming aspect of large scale programs. Hard experience has emphasized the importance of a well designed data capture system at an early stage of the project.

° Quality Assurance

The likely success of any source apportionment program is directly tied to the quality of the field program protocols, sample handling procedures, instrument siting, laboratory QA and data validation procedures. Failure of the program design to adequately address quality assurance needs tends to compromise the validity of the results.

° Sources To Be Characterized

The number and nature of the sources to be chemically (or morphologically) characterized, the number of samples to be collected for analysis and the analytical work to be conducted may potentially be important considerations in developing the program budget. In addition to the data capture activities, resources must be allocated to the interpretation and documentation of the source composition data.

° Meteorological Data Requirements

The number, location and instrumentation to be included in surface meteorological stations can be an important cost, especially when data capture,

instrument servicing and personnel costs are considered. The inclusion of a program to capture upper air data and the staff time required to process and interpret the data, can be extremely costly unless upper air soundings are restricted to specially selected periods.

° Data Analysis and Reporting Requirements

The scope and timing of the analysis and reporting requirements, level of technical support required and degree of dependance on consultant assistance will play a major role in program design and funding requirements.

During development of the program design, a few key concepts should be upheld: (a) the most cost effective approach to sample analysis has proven to rest on selection of a few, critical samples rather than wholesale analysis of all collected filters, (b) program emphasis on quality assurance, and (c) allocation of sufficient resources (funding and time) to assure that data analysis and reporting tasks can be adequately completed.

3.1.2 Development of Source Composition Data

Since nearly all of the receptor models require a knowledge of the chemistry or morphology of source emissions, the development of a library of emission chemistry data or particle reference samples (or both) are often required. Although source emission chemistry is often obtained from the literature, experience has demonstrated the value in collection and analysis of size-resolved samples from local sources, just as locally derived source emission data is preferable to published emission factors.

Source composition data reported in the literature can be successfully used if care is taken to insure that reported chemical composition of a source emission is reasonably representative of the airshed being studied. For example, motor vehicle particulate emission composition reported for St. Louis (1978) may not be representative of 1981 auto emissions in Los Angeles. Adjustments to the composite transportation emission composition must often be made to adjust for differences in the leaded/unleaded fuel use or the relative ratio of diesel to light duty motor vehicles in the two cities. Since the emission composition will vary as a function of the chemical composition of the process input materials, the chemical "fingerprints" of particles emitted from two different steel mills, for example, may be very dissimilar.

Until such time that a comprehensive, size resolved particulate emission characterization data base can be developed, analysts interested in applying chemical receptor models will have to research (and adapt) source data reported in the literature or conduct tests of local sources. Although programs are now underway within EPA to expand the receptor model source characterization library, the need to adapt emission chemistry to reflect local sources will still remain. Default emission chemistry values need to be developed to meet the needs of those that wish to use chemical receptor models as a screening tool.

In many studies, measurements of local sources may be required to supplement information obtained from the literature. In these cases, a source sampling program must be designed which considers four key issues:

° The source characteristics measured should reflect those perceived at the receptor. Because of condensation of vapors, deposition of large

particles and the loss of volatile species as the plume is transported downwind, samples taken from stacks (especially those at high temperature) may not provide data that are chemically or morphologically similar to the aerosol measured at the receptor several kilometers away. The tendency to neglect fugitive emissions that are difficult to source test is a further problem. Fortunately, many of these difficulties can be minimized through the use of size resolved source testing trains that employ stack gas dilution systems. Plume sampling from aircraft or tethered balloon have also been used. Attempts to deduce source emission characteristics using ambient samplers located in expected areas of maximum impact have also been reported.[24]

° The program design must be targeted at facilities which are believed to be representative of similar source within the study area. Professionals that are familiar with local manufacturing processes within the airshed should be consulted during the selection process. Ideally, the facilities tested should be those that have been shown, through dispersion modeling analysis, to have significant impacts at the receptor(s) of interest.

° All major emission sources should be chemically characterized, either through a source testing program or by adaptation of literature values. Existing emission inventory, microinventory, and dispersion modeling data are typically used as a guide in evaluating the adequacy of the emission characterization data base.

° The source testing protocol must be consistent with the requirements of the analytical techniques to be used. Unfortunately, stack gas dilution sampling designed to capture fine and coarse mode particles on chemically inert

filters are not well documented in the open literature or commercially available. Several sampling trains have been developed by receptor model researchers, however. Further information on sampling train configurations can be obtained by contacting EPA's Technical Support Staff, Industrial and Environmental Research Laboratory (IERL), Research Triangle Park, North Carolina 27711.

Volume II of this series discusses the application of data reported in the literature and source sampling program design in greater detail.[15]

3.1.3 Data Interpretation

The interpretation stage consists of applying one or more of the receptor model approaches to interpreting the chemical and physical data generated. If the objective of a source apportionment study is the support of effective control action, the level of confidence required to initiate action may be established with a single receptor model interpretive approach or it may require information from additional interpretive approaches such as wind sector analysis, dispersion models, microscopy, etc. The first step of any source apportionment study should therefore include a thorough review of the potential sources, their chemistry and time dependence, if the highest level of confidence is to be established in the final results.

3.2 Typical Program Costs

Although much is heard of the large scale source apportionment studies typically costing hundreds of thousands of dollars in funding, the application of receptor model techniques need not necessarily be an expensive, resource intensive effort. While the actual cost of a source apportionment study will depend in large measure on the scope of the program, a crude estimate of likely costs have

been prepared for three example cases.[25] Component costs, based on 1980 prices, used in these examples are shown in Table 8.

Table 8. Source Apportionment Study Costs: Program Component Estimates

Item	Cost Range	Estimate Used
Ambient Sampler	$200 to $10,000 each	$5,000
Filter Media	$0.25 to $3.00 each	$2
Filter Mass Measurements and Logistics	$1.00 to $10.00 per filter	$5
XRF Elemental Analysis	$15 to $30 per filter	$25
Total Carbon Analysis	$10 to $20 per filter	$15
Elemental and Organic Carbon	$25 to $50 per filter	$35
"Short" INAA*	$20 to $50 per filter	$30
"Intermediate" and "Long" INAA**	$50 to $150 per filter	$70
Microscopy	$200 to $500 per filter	$300

* "Short" Instrumental Neutron Activation Analysis (INAA) analysis includes Na, Mg, Al, Br, V, Ti, K, Mn.

** "Intermediate" and "Long" INAA analysis provides data on As, Sb, Co, Cr, Fe, Hg, Sb, Se, Zn and numerous other trace elements.

Example Case 1: Minimal Program ($5,000)

A minimal program costing no more than $5,000 would consist of a one-year study of source impacts at a single sampling location at which TSP NAAQS violations occur. By sampling every sixth day, concurrent with routine hi-vol measurements, samples can be collected on an inexpensive TSP sampler in a form suitable for direct mass and chemical analysis. Appendix I describes a low volume TSP sampler that has been used successfully in several receptor model studies. A separate sampler is required to insure that the aerosol is collected on a filter substrate that is compatible with XRF analysis requirements. Source composition data from literature sources (adapted to the airshed under study) can be supplemented with source characterization samples (ten filters) from a few key sources. Typical costs for such a program include:

° Low-volume ambient TSP sampler*	$ 900
° Teflon-substrate filters (80)	$ 300
° Mass measurements and logistics	$ 400
° XRF analysis (poor detection limits)	$ 400
° Chemical Mass Balance calculations	$1,200
° Data analysis and reporting	$1,000
Total	$5,000

* See Appendix I

These costs assume that (a) field measurements are conducted by agency or company air monitoring staff and that site rental, power and maintenance expenses are absorbed by the agency, (b) source apportionment for ambient TSP is required to identify annual and 24-hour impact, (c) that source testing equipment and associated costs are paid by the agency, and (d) that agency staff develop the source matrix data.

Example Case 2: Moderate Program Costs ($26,000)

An expanded, four station program sampling on an every sixth day schedule for TSP only can be implemented for about $25,000. Such a program could provide for improved analytical sensitivity, ion and carbon analysis, improved source characterization and data interpretation. A key element in improving the cost-effectiveness of the program is selection of 30 days for sample analysis based on a review of annual meteorological patterns that can be reflected in the days sampled. Assuming 240 ambient filters, 30 source samples and 30 samples analyzed for quality assurance purposes, cost can be cut by analyzing only 180 of the 240 ambient filters. In this example, component costs are as follows:

° Low volume ambient TSP samplers*	$ 4,000
° Teflon substrate filters	$ 900
° XRF elemental analysis (moderate detection limits)	$ 3,600
° Elemental and organic carbon analysis	$ 4,200
° Ion analysis	$ 5,400
° CMB calculations	$ 2,700
° Data interpretation and reporting	$ 4,000
Total	$26,300

* See Appendix I

As in the first example, many program costs related to air monitoring, source testing and source emission characterization tasks are not reflected in these figures. These tasks are, however, well within the capabilities of most regulatory agencies using staff professionals.

Example Case 3: Expanded Program Cost ($100,000)

Further expansion of the program objectives noted in Case 2 to include TSP, fine and coarse mode particle source apportionment, more comprehensive source characterization, and improved airshed input analysis are illustrated below. By sampling on an every third day basis to improve opportunities for episode analysis, this program would provide for the capture of 1444 ambient and 100 source filters, 150 samples analyzed for quality assurance and blanks, all 1700 samples measured for mass and 700 samples to be chemically analyzed (40 days selected for analysis). Component costs are itemized below:

° Dichotomous samplers (leased)	$10,000
° Teflon-substrate filters	$ 5,100
° Mass and logistics	$ 8,500
° XRF (best detection limits)	$18,400
° Elemental and organic carbon analysis	$ 5,600
° Ion analysis	$22,080
° "Short" INAA analysis	$22,080
° CMB calculations	$ 7,360
° Data interpretation and reporting	$10,000
Total	$99,130

More ambitious programs designed to apportion light extinction, provide greater spatial coverage and develop data required for meteorological data base improvements would, of course, expand program costs greatly. The key point to be made here is that the application of receptor model techniques need not be an extremely costly, research program. Experience in the use of these methods to resolve routine problems in air resource management has shown receptor techniques to be practical tools.

3.3 Program Management

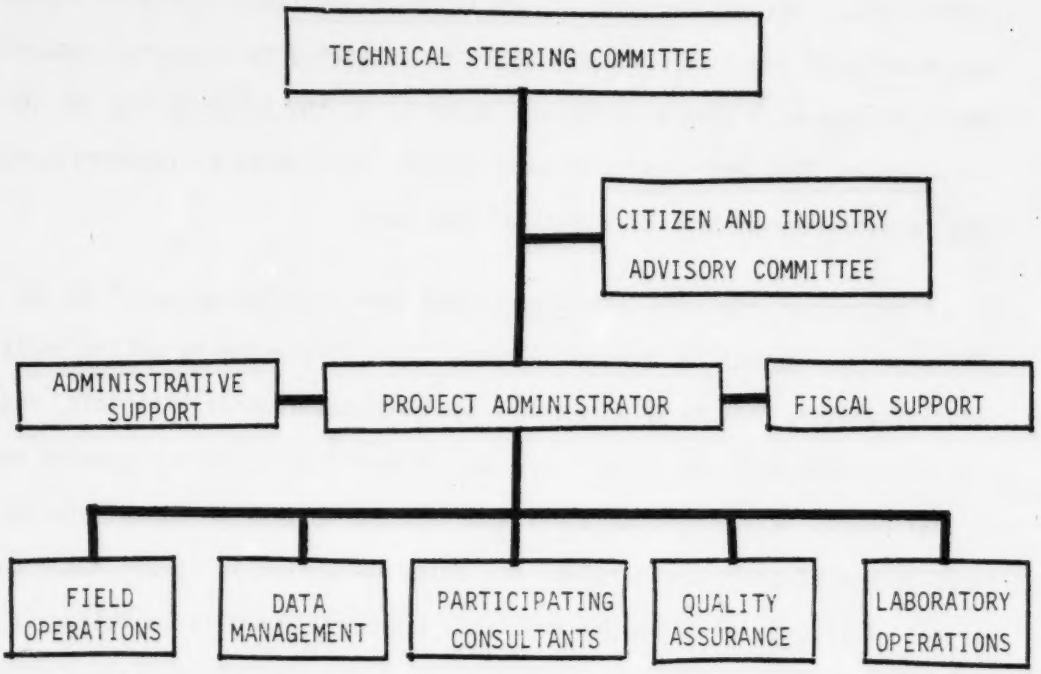
The degree of program management required will depend to a great extent on the likely consequences of the results to the community and those sources likely to be regulated. The following discussion is directed to those who intend to conduct receptor model studies in support of the control strategy development process. Regardless of the potential importance of the study results to the community, however, capable program management is of central importance to the successful completion of receptor model studies. Key elements of the program management are discussed below.

A detailed work plan for accomplishing the general tasks of the study should be developed by those individuals responsible for conducting them. The work plan should include an identification and description of specific tasks to be performed and a detailed schedule for their completion. The schedule should show the projected start and end date of each task, significant milestones to be reached and tasks that must be completed before other activities can commence. A staffing and management plan assigning persons responsible for each activity is also useful.

In addition to work plans, an itemized budget listing costs associated with major program tasks should be developed for both projected and actual expenditures overtime. Standard operating procedures used in the field and laboratory programs are important to the project's quality assurance program as are proper procedures for instrument calibration, verification of analytical methods and data processing protocol.

Figure 4

Organizational Chart for
Receptor Oriented Source Apportionment Project



It may be advisable to include in the planning and implementation of the study, representatives of organizations (and the general public) who must make regulatory decisions based on the results of the study. The two key ingredients in the organization of a receptor model study are a technical steering committee and an advisory committee with a broad base of public, government and industrial representatives.

The technical steering committee should be composed of individuals responsible for the different phases of the project. This might include field and source sampling programs, sample analysis, data management, meteorological analysis, and project administration. These representatives should come primarily from the

parent organization conducting the study but could also draw on representatives from other government agencies, environmental organizations and participating consultants. Responsibilities of the technical advisory committee include preparation of the study design and review of contractor-prepared documents to the committee must assure technical integrity of the study during its implementation by frequent updates of work status, resolution of technical problems and coordination of all components of the study.

The project advisory committee should have representatives from the public at large, environmental interest groups, those interested in public health, local industry, Chamber of Commerce, public transportation officials, and a representative from the Mayor's office. Figure 4 outlines a suggested organizational chart. Advisory committee functions are to provide input into the development of program objectives and study design and to inform their constituency of program progress and results. The most important objective is to ensure that advisory committee participants appreciate the technical foundation of the program. Community confidence in potentially unpopular control action can be greatly strengthened through an active advisory committee program.

4.0 APPLICATIONS OF RECEPTOR MODELS

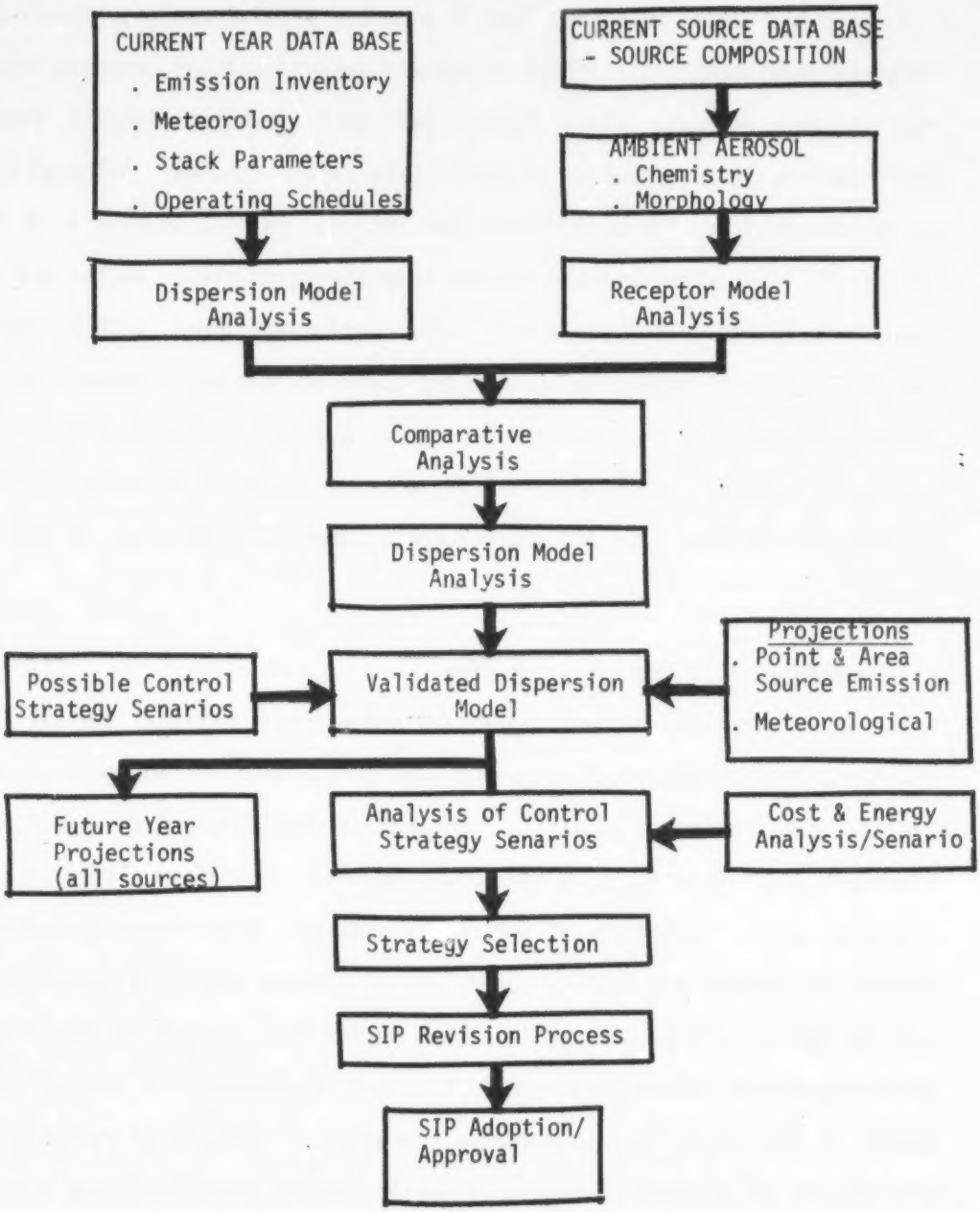
Receptor models have been used in a number of applications including control strategy development, stationary source enforcement actions, demonstration control strategy analysis, source impacts related to "bubble" analysis, dispersion model validation, and general airshed source impact studies. Although optical microscopy has been the most widely used receptor method, studies in at least 37 cities utilizing chemical mass balance have been completed. Factor and regression analysis have also been widely used. Other techniques, such as spatial and temporal analysis, have been extensively used over the years because of their simplicity and value. In those cases where an impact analysis of an existing source is required, receptor models may provide an impact estimates of comparable (or better) accuracy than dispersion models, especially in areas of complex terrain.

4.1 Development of Control Strategies

Control programs designed to attain and maintain National Ambient Air Quality Standards for total suspended particulate usually require that control strategies are designed to attain standards at some future date specified in the Clean Air Act. This requires regulatory agencies to analyze alternative control scenarios using projections of future air quality. Since receptor models cannot be used to project air quality conditions or analyze control alternatives in all but the most simple of cases, dispersion models must be used to demonstrate the effectiveness of future strategies. Figure 5 illustrates the role of receptor models in the control strategy analysis process. Inclusion of receptor model analysis in the dispersion model validation program helps to insure that control strategy scenario analysis is based on a dispersion model that has been proven to reasonably predict impacts from specific sources.

FIGURE 5

SOURCE/RECEPTOR MODEL PATHWAYS
TO CONTROL STRATEGY ANALYSIS



Receptor model studies of the aerosol mass transported into an air quality maintenance area (AQMA) provides important information as to the source composition of the "background" aerosol. If the analysis identifies an important upwind source with an impact and projected growth rate critical to the AQMA's ability to maintain NAAQS, action may be needed to regulate the source. In those cases where receptor model analysis of the background aerosol is not conducted, regulatory agencies responsible for strategy development may have little knowledge of the identity, impact or potential emission growth of sources outside of the AQMA boundary.

Once a strategy has been implemented, however, receptor model techniques can be used to track the impact of important sources and source groups (such as crustal components-unpaved and paved road dust, soil dust, etc.). Other applications include studies of source impacts during periods of air stagnation as input to Emergency Action Plans, analysis of the impact of wind-entrained soil dust on NAAQS attainment and a host of others.

4.2 Validation of Dispersion Models

Air quality data have long been used to assess the ability of dispersion models to simulate measured air quality. This process, called model validation, is intended to lend support to the dispersion model's predictions or provide a basis for re-evaluating the dispersion model's data base or assumptions. In particulate modeling, predictions have traditionally been compared to ambient total suspended particulate (TSP) measurements. Unfortunately, past experience has shown that particulate matter dispersion models frequently fail to predict a significant portion of the measured TSP mass, largely because of the difficulty in inventorying (and accurately simulating), fugitive dust sources that frequently dominate the TSP mass.

In those cases where dispersion model estimates are reasonably well matched to the TSP mass, little evidence of the model's ability to accurately predict the impact of a single source, or group of sources, exists without some form of receptor model analysis. In addition, "traditional" forms of dispersion model validation, which rely on comparisons of measured TSP mass to dispersion model predictions, cannot provide the level of information needed to identify errors in the impact estimates for specific sources. While the ability of current receptor models to address these concerns is limited, experience has shown receptor model results to be of great value in improving dispersion model performance.

The source-receptor (S/R) model validation process includes three key tasks (a) experimental study design, (b) model comparisons, and (c) dispersion model improvements:

4.2.1 Study Design

The design of the S/R model analysis should include many of the considerations discussed in Chapter 3 of this document. Although existing ambient aerosol chemistry, source composition data, emission inventory and meteorological data can be used for the S/R analysis, the level of success of the receptor model analysis program in identifying the impact of sources of interest will be greatly enhanced if the project design is tailored to the receptor method, sources and airshed of interest.

A basic requirement of the S/R model comparison is one of concurrent data set development. This requires that the dispersion model analysis be conducted for the same days, at the same sampling sites, as the receptor model analysis. The project experimental design, then, ideally requires that all of

the input data required for both the dispersion and the receptor model be developed for the period in time during which the ambient monitoring program is operational. Emission inventories, specifically tailored for the period of field sampling, should be used.

The first step in building the program design should be one of selecting the "target" sources--those emission sources for which the S/R model analysis is to be conducted. If the dispersion model simulates both area and point sources, two sources within each group should be selected. By including two types of area sources and two point sources in the comparison, a measure of the dispersion model's ability to simulate both types of sources is gained. "Target" sources are those sources which ideally meet the following criteria:

(a) The chemical, morphological or variable nature of their emissions allows their impact to be accurately identified by receptor models.

(b) They are major emission sources thought to impact the study area.

(c) Accurate, complete emission inventories, stack parameter data and source operating schedules are available.

(d) The composition of the source emissions is relatively constant and well characterized.

The area source which best meets these criteria is leaded auto exhaust. Soil and road dust have also been used because of (a) their importance as a major source impacting TSP concentration, and (b) the ability of receptor models to identify soil-like particles (as a source group). Resolution of soil and

road dust into distinct sources (paved roads, unpaved roads, etc.) is, however, difficult in those areas where both sources are found. Point sources used as analysis targets have included residual oil combustion sources (by reason of their distinct Ni and V tracers) and ferromanganese steel production which is characterized by its rich fine particle Mn content.

Since the dispersion model estimates only encompass those "local" sources included in the emission inventory, a compatible receptor model analysis must be developed through a program of "background" and "urban" aerosol analysis. Auto exhaust particles, for example, detected by the receptor model analysis of incoming air, must be subtracted from the auto exhaust component measured at the urban receptor to provide an impact estimate consistent with the dispersion model. Selection of the "background" monitoring site location, and the representativeness of the urban site, are most important to the S/R comparison.

The sampling network design must also include sufficient spatial coverage and temporal resolution to allow comparison of the S/R model results under a number of different transport and dispersion conditions. In addition, sampling equipment and sample analysis techniques used in the network must be compatible with the receptor model requirements.

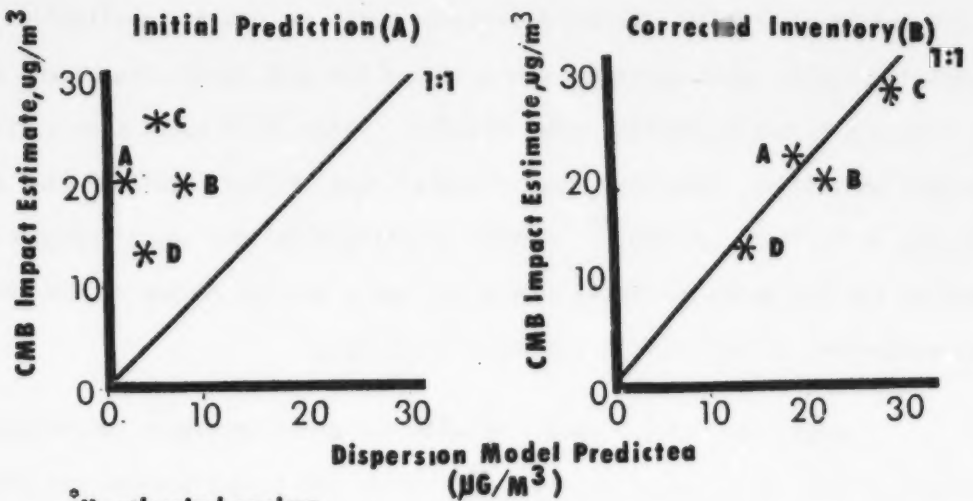
Following completion of the aerosol sampling program and development of dispersion model input data, an independent analysis of source impacts, using both model approaches, should be completed. Independent model validation procedures should then be used to judge the validity of each model's results.

4.2.2 Comparison of Model Results

Following validation of results from each model, annual average dispersion model simulations are prepared for each of the target sources for those sampling locations for which receptor model results are available. "Local" receptor model estimates are prepared for each target source and plotted in relation to the dispersion model results. Figure 6(A) shows such a plot for results of initial dispersion model-Chemical Mass Balance predicted road dust impacts in Portland, Oregon.[26] Further investigation into any discrepancies between the two model estimates should include a general review of the strengths and weaknesses of both models and their input data.

Comparisons of S/R models results for other transport conditions, seasons of the year, source emission activities and target sources can often resolve discrepancies by leading the analyst to deficiencies in one of the two models. Analysis of road dust impacts in Portland, for example, indicated consistent dispersion model underpredictions which were more severe at sampling sites in areas subject to fugitive dust impact (Sites A and C) than at commercial (Site B) and residential locations (Site D). The degree of dispersion model underprediction is indicated by the horizontal distance of the point to the 1:1 slope line, assuming that the receptor model results are more nearly correct. In the example case, optical microscopy and microinventory results for the Portland sites clearly supported the CMB results rather than those of the dispersion model.

Figure 6
Portland, Or. Dispersion Model –
Predicted Road Dust Impact*



*North wind regime

4.2.3 Disperion Model Improvement

Following an analysis of the possible reasons for the underprediction, corrective action can often be taken, thus improving the user's confidence that impacts of individual sources can be predicted with reasonable accuracy. In the case of the Portland analysis, land-use specific road dust emission factors were adopted, replacing an emission factor which ignored the differences in soil dust trackout between industrial, commercial and industrial areas. As a result, the emission inventory was increased by 600% and the systematic underpredictions in the dispersion model estimates were corrected.[27] Figure 6(B) shows the S/R comparison based on the corrected emission inventory.

Upon completion of the S/R model validation process, the analyst can have increased confidence in the overall ability of the dispersion model to simulate both the impact of a large number of sources and in individual sources as well.

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APPENDIX I

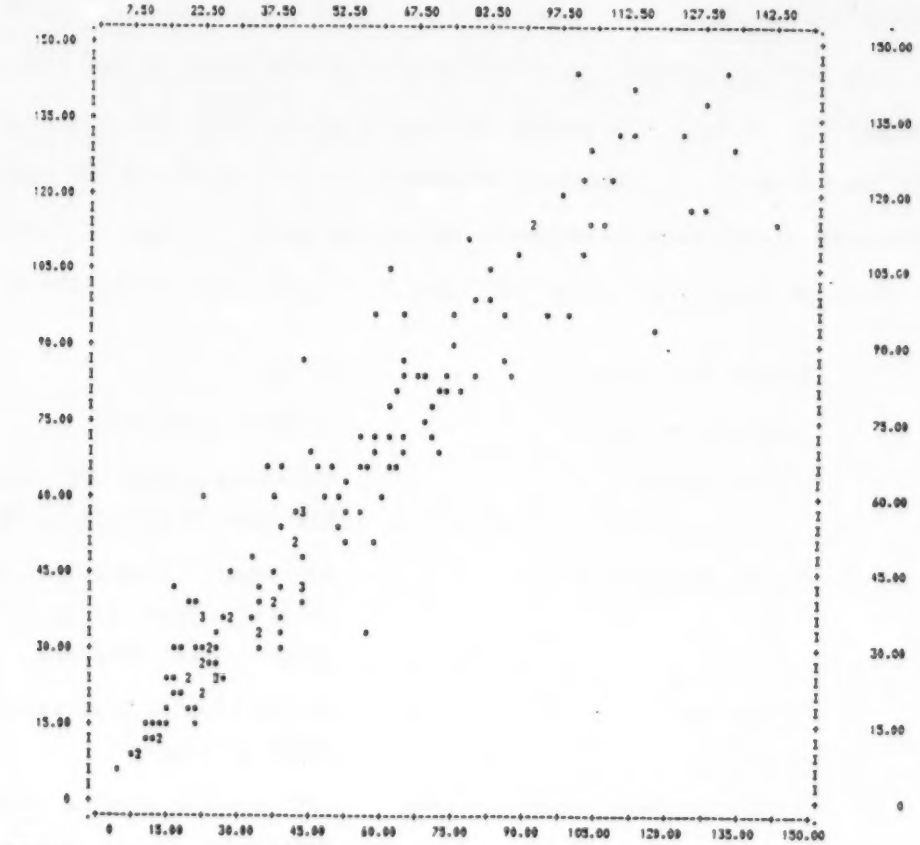
Low-volume TSP Sampler

The low-volume TSP sampler described herein was designed to capture, on an inert substate suitable for x-ray fluorescence and ion analysis, the same total particulate fraction that is measured by the hi-volume sampler. Inlet geometry, air flow velocity and cost were the three most important factors that influenced the design. To date, the sampler has been used in three Oregon aerosol studies with good results. A comparison of aerosol mass collected by the sampler and collocated hi-vol federal reference method equipment is shown in Figure A. Construction details are shown in Figure B. Sampler specifications are as follow:

Sample flow rate	80 lpm
Sampling period	24 hours (typical)
Filter medium	Cellulose acetate (47 mm), 1.2 micron Millipore Corporation, RA
Filter holder	Nucleopore Corporation, No. 430400 aerosol holder, 47 mm (with quick connect fitting)
Filter cap	4" PVC plastic pipe cap (Yardley 89644 or similar)
Filter assembly holding flange	.05" acrylic plastic cemented to filter cap

IMACS SAMPLER COMPARISON 80/03/21. 12.49.11.

SCATTERGRAM OF (DOWN) HVMASS TSP MASS BY FRM
(ACROSS) LVMASS LOW-VOL TSP



STATISTICS..

CORRELATION (R)-	.94491	R SQUARED -	.89285	SIGNIFICANCE R -	.00001
STD ERR OF EST -	11.73573	INTERCEPT (A) -	7.44834	STD ERROR OF A -	1.79252
SIGNIFICANCE A -	.00003	SLOPE (B) -	1.03934	STD ERROR OF B -	.02920
SIGNIFICANCE B -	.00001				

Figure A. TSP Mass Comparison (Low-vol Versus Hi-vol TSP Samplers)

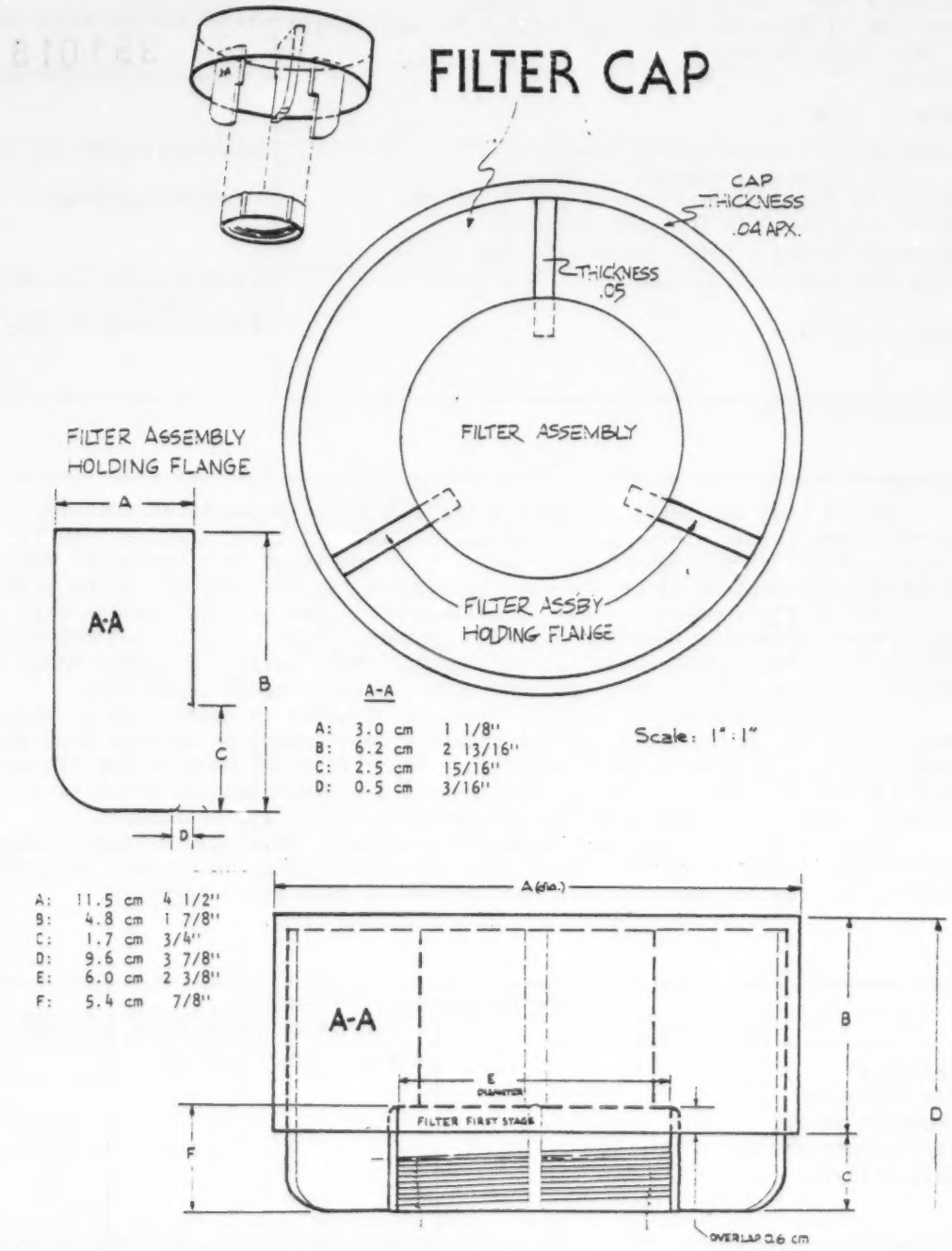


Figure B. Low-volume TSP Sampler Detail